AGSO Journal of Australian Geology & Geophysics, 16(5), 731–757

A non-marine Lower Cretaceous rift-related epiclastic volcanic unit in southern Australia: the Eumeralla Formation in the Otway Basin. Part II: fluvial systems

E. Anne Felton[1]

Relationships, thicknesses, and palaeocurrent and other sedimentary data applying to facies associations in Eumeralla Formation outcrops in the eastern Otway Basin distinguish at least three discrete depositional systems (A–C). Each system is characterised by high-energy fluvial flows in broad channel tracts.

The multistorey sandstone bodies of system A, between Cape Otway and Apollo Bay, are up to 70 m thick and contain varying proportions of basement-derived quartzose gravel and sand intermixed with mainly volcaniclastic sand. Interchannel siltstones also up to 70 m thick separate the sandstone bodies. Palaeocurrents in system A have an overall southerly trend. This system is interpreted to represent deposition in a medial alluvial fan to proximal braided-stream system.

System B occurs around Moonlight Head, and may extend southeast to Rotten Point. It is characterised by multistorey sandstone bodies up to 14 m thick separated by siltstones of similar thickness which locally contain thin coal beds, rooted horizons, and reddened soil profiles. It lacks basement-derived gravel. Palaeocurrents trend northeasterly to northwesterly. The sediments of system B accumulated on a medial to distal braid plain.

Facies associations and fluvial architecture of system C, seen in outcrop north of Skenes Creek, resemble those of system B, from which it is distinguished by consistently northwest palaeocurrent vectors, a basement-derived gravel component, and the absence of debris flows and volcanic pebbles. System C also represents deposition on a braid plain or in a braided-river system.

The three depositional systems are accommodated in a model for the Eumeralla Formation which suggests that its volcanic detritus was derived largely from infrarift volcanic complexes in the axial parts of the Otway rift basin, which during the Aptian–Albian lay to the south of the present coastline. A volcaniclastic apron spread northwest to northeast across the basin (system B). Elevated basement blocks shed quartzose detritus into flanking alluvial fans, the more distal parts of which mixed with volcaniclastic detritus (systems A, C). The onset of axial volcanism in the Aptian may have displaced a former westerly axial drainage towards the northern basin margin (system C).

Introduction

Part I of this paper describes four lithostratigraphic units comprising the Eumeralla Formation (Eumeralla I–IV), and presents an interpretation of their depositional environments, mainly from subsurface data. Part II describes the facies architecture and facies associations of those parts of Eumeralla II and Eumeralla III which crop out in the eastern Otway Basin. These associations, together with other sedimentary data, discriminate at least three depositional systems, and lend further support to the environmental interpretation of Eumeralla II and III.

Methods and data

The field methods used to gather sedimentary data are described in part I. Field locations are shown in Figure 1.

Six long and seven vertical profiles (Appendix) are representative of outcropping lacustrine and fluvial systems (Eumeralla II and III) respectively. The following discussion of facies associations is based on the profile descriptions.

Facies associations, Eumeralla II and III

Lithostratigraphic units Eumeralla II and III can be described in terms of their facies associations, sediment bodies distinguished by overall geometry, and internal architectural elements comprising assemblages of lithofacies. Each association represents a particular part (e.g., fluvial channel tract) of a larger depositional system. The internal arrangements of facies associations reflect the depositional processes and sedimentary controls (Miall 1985), while the relationships between the

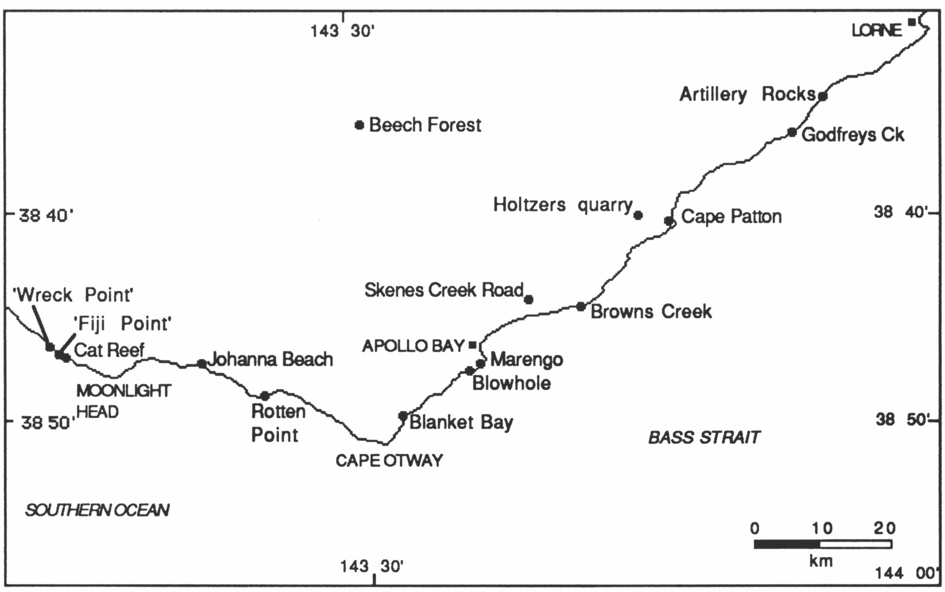

Figure 1. Field locations.

[1] Department of Geology, The University of Wollongong, Wollongong, NSW, Australia; present address: SOEST Hawaii Institute of Geophysics and Planetology, University of Hawaii, 2525 Correa Road, Honolulu, HI 96822, USA.

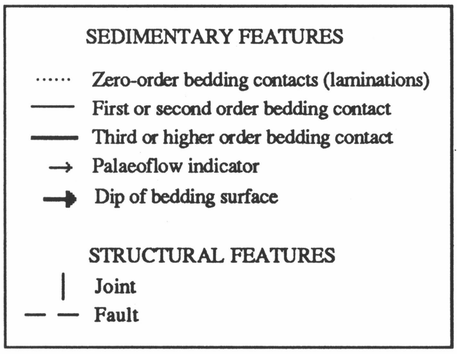

Figure 2. Key to long profiles.

associations define the character of the depositional systems.

The several architectural element classification schemes proposed for fluvial systems (e.g., Friend 1983; Allen 1983; Miall 1985) vary in complexity, but in general rely on excellent three-dimensional exposures for their application. Although the Eumeralla Formation is well exposed in cliff sections and wave-cut platforms in the eastern Otway Basin, the overall lack of three-dimensional exposures limits the application of Miall's (1985) classification. However, the simpler schemes of Friend (1983) and Allen (1983) proved useful starting points for developing the sedimentation models described later in this paper.

Fluvial-channel-tract facies association

The lithofacies assemblages present in this association are listed in Table 1. The association is dominated by plane-bedded and low-angle cross-bedded medium- to fine-grained sandstone (facies Sh and Sl; Table 2) and climbing-ripple-laminated fine sandstone (facies Src).

Facies architecture

All the geomorphic and depositional elements of modern fluvial channel tracts — channels, bars, bar complexes, and banks — have been observed in Eumeralla III sandstones (Appendix; Figs. 2–15). The relationships of these depositional elements were illustrated by Walker & Cant (1984). Each is characterised by one or more particular lithofacies, as described and interpreted in part I.

Single sets of lithofacies are separated by first-order contacts. Groups of genetically related lithofacies in bars, bar complexes, and dunes are separated by second-order bedding contacts which are usually discordant or concordant erosional (Allen 1983); the amount of erosion varies along the contact (e.g., surface **b**, Johanna Beach profile; Appendix; Fig. 12). These groups correspond to the 'storeys' of Friend et al. (1979), and the bounding erosion surfaces to their description of 'storey-scours'. All the channel-tract sandstone bodies observed in Eumeralla III are multistorey.

The sandstone storeys form sheets, or very broad channel forms with width>>depth (e.g., at Cape Patton; Appendix; Figs. 3, 4a, 4b), which are locally mud-draped. They are separated by sharp, flat to irregular scoured contacts of third or higher order (cf. Cant & Walker 1978), which are usually discordant erosional. These major scour surfaces are usually overlain by discontinuous stringers of muddy siltstone intraclasts (lithofacies Gs; Fig. 15); intraclast-supported massive conglomerate is locally present in scour hollows (fig. 16 in part I). In sandstone sequences lacking intraclasts, both second- and third-order contacts can be difficult to discern, particularly in weathered, inaccessible cliff sections (e.g., Fig. 3).

Variable amounts of erosion associated with the scour surfaces are reflected by the presence of intraclasts (lithofacies Gmi, Gs), and the overall lack of fining-upwards sequences commonly associated with channel occupation and abandonment. Where completely developed in Eumeralla III, a typical fining-upwards channel-fill sequence consists of basal Gmi or Gs overlying a third- or higher-order contact, succeeded by medium-grained Sh/Sl with or without St, then fine-grained Src, Sr, and Fl/Fm. However, finer-grained lithofacies (Sr, Fl, Fm) are generally eroded away, and appear only as intraclasts, mainly lithofacies Gs. Although making up less than 5 per cent of the channel-tract thickness, Gs is very common.

Channel margins and banks rarely crop out. Only one has been recognised unequivocally, by its associated levee: at Cape Patton lookout, a sandstone bed at the base of a palaeochannel cuts into overbank siltstone and coal, and wedges out against a levee; an overlying sandstone passes laterally into interbedded sandstone and siltstone, also interpreted as a levee (Figs. 4a, 4b).

Sandstone body geometry

Large-scale tabular or sheet geometry can be inferred for at least some Eumeralla fluvial-channel-tract sandstone bodies, although the dimensions of the bodies relative to outcrops

Table 1. Eumeralla facies associations: constituent facies

	Fluvial channel tract		*Fluvial flood plain*		*Lacustrine*	
Letter code	*Channel floor*	*Bars*	*Flood basin*	*Levee*[1]	*Basin*	*Margin*
Gmi[2]	X					
Gm	x					
Gs	X	x	x			
Sb	x					
Sm	x					
Sh	X	X	X	x	x	
Sl	X	X	x			x
Ss	X		x			
St	X	x	x			x
Sp		x	x			
Sr		x	X	X	X	X
Src		X	x	x		
Fl		x	X		X	x
Fm		x	X	X	X	X
C			x	x	x	x

[1] Only two examples observed.
[2] Facies codes generally follow the scheme of [Miall, 1978 #388]. See Table 2 for facies descriptions.
X = common occurrence; x = uncommon occurrence; no symbol = not observed.

preclude mapping their full extent. Sandstone body dimensions almost invariably exceed outcrop dimensions, and have overall minimum lateral dimensions of tens to hundreds of metres (Table 3).

Two other observations support the inference of sheet form for channel-tract sandstone bodies. Facies and facies architecture in the sandstone bodies, whose wide lateral extent (Table 3) can be unequivocally demonstrated, are similar to those observed in outcropping thick sandstone bodies throughout Eumeralla III, and imply similar depositional processes and hence channel formation and filling. Also, evidence for large-scale channel incision is lacking. As described above, third-order basal contacts of the sandstones, although locally scoured, are flat overall, and channel-bank contacts are rare. Gradational top contacts to the sandstones are also moderately flat.

The geometry and architecture of the sandstone bodies, their relationships with flood plains (see below), and lack of evidence of channel confinement suggest that deposition took place in very broad tracts composed of vertically and laterally stacked broad channels whose widths greatly exceeded their depths.

Fluvial-flood-plain facies association

The lithofacies present in this association are listed in Table 1. Although not as well represented in outcrop as the fluvial-channel-tract facies association, the flood-plain facies association is widely distributed in Eumeralla III — for example, at Cat Reef and west of Johanna Beach (Table 4).

Flood-plain deposits

Geomorphic and depositional elements of flood plains include small channelways (flood-plain distributary channels, moderately flat interchannel areas inundated at high flood stages, and basin-like shallow depressions that were the locations of flood-plain lakes and swamps in those areas; Popov & Gavrin 1970; Simpson & Doutch 1977). These elements comprise the flood basin. Levees are elevated areas forming the most proximal part of the flood plain relative to the river channel (Kesel et al. 1974).

Flood-plain deposition in the outcropping Eumeralla Formation is inferred for mainly fine-grained sandstone and siltstone deposits which are tens of metres thick and hundreds of metres in lateral extent, and occur between channel-tract sandstones. Compositional details of several flood-plain-inter-

Table 2. Summary of sedimentary facies, Eumeralla Formation.

*Facies**	*Description*	*Major associated facies*	*Occurrence*	*Interpretation/ bedforms*
Gmi	Massive clast-supported conglomerate; intraclast-dominated; lacks internal structure	Gs, Sl	Scour hollows	Scour fill; ?debris flow
Gm	Massive sandy conglomerate; pebble imbrication to structureless; mainly exotic clasts	St	Locally in channel tracts	Bar; channel fill
Gs	Mudclast-stringer conglomerate	Gmi, Sl, Sh	Scour surfaces	Rip-up clasts from stream bank or redistributed Gmi
Sb	Back-set cross-bedded sandstone	Sh	Locally in channel tracts	Upper-regime flow; locally developed chute-and-pool
Sm	Massive (structureless) sandstone	Sh	Channel tracts	?Hyperconcentrated flow; locally developed antidunes
Sh	Plane-bedded sandstone	Sl, St, Src	Channel tracts; sheets in overbanks	Upper-regime plane-bed flow; bars and sheets
Sl	Low-angle cross-bedded sandstone	Sh, St, Src	Channel tracts; thick sheets in overbanks	Upper-regime plane-bed to transition flow; forward and lateral accretion of bars and sheets
Ss	Scour-filling low-angle cross-bedded sandstone	Sh	Channel tracts; thick sheets in overbanks	Upper-regime flow
St	Trough-cross-bedded sandstone	Sh, Sl, Sp	Channel tracts; thin sheets in overbanks	Lower-regime flow; distal or waning floods; dunes
Sp	Planar tabular cross-bedded sandstone	St	Channel tracts; thin sheets in overbanks	Lower-regime flow; waning floods; sand waves, transverse bars
Src	Climbing-ripple-laminated sandstone	Sh, Sl	Channel tracts; thin sheets in overbanks	Rapid sediment fall-out; sudden loss of flow strength due to waning flood or flow diversion
Sr	Ripple-laminated fine sandstone, wavy laminated fine sandstone	Fl	Thin beds in channels and overbanks	Low flow strength; sinuous-crested ripples
Fl	Laminated, wavy-, and cross-laminated siltstone and mudstone	Sr, Fm	Lenses and thin beds in channels and overbanks	Suspension fall-out
Fm	Structureless siltstone and mudstone	Sr, Fl	Tops of channel tracts	Suspension fall-out; includes seat earths

* Based on lithofacies codes of Miall (1978).

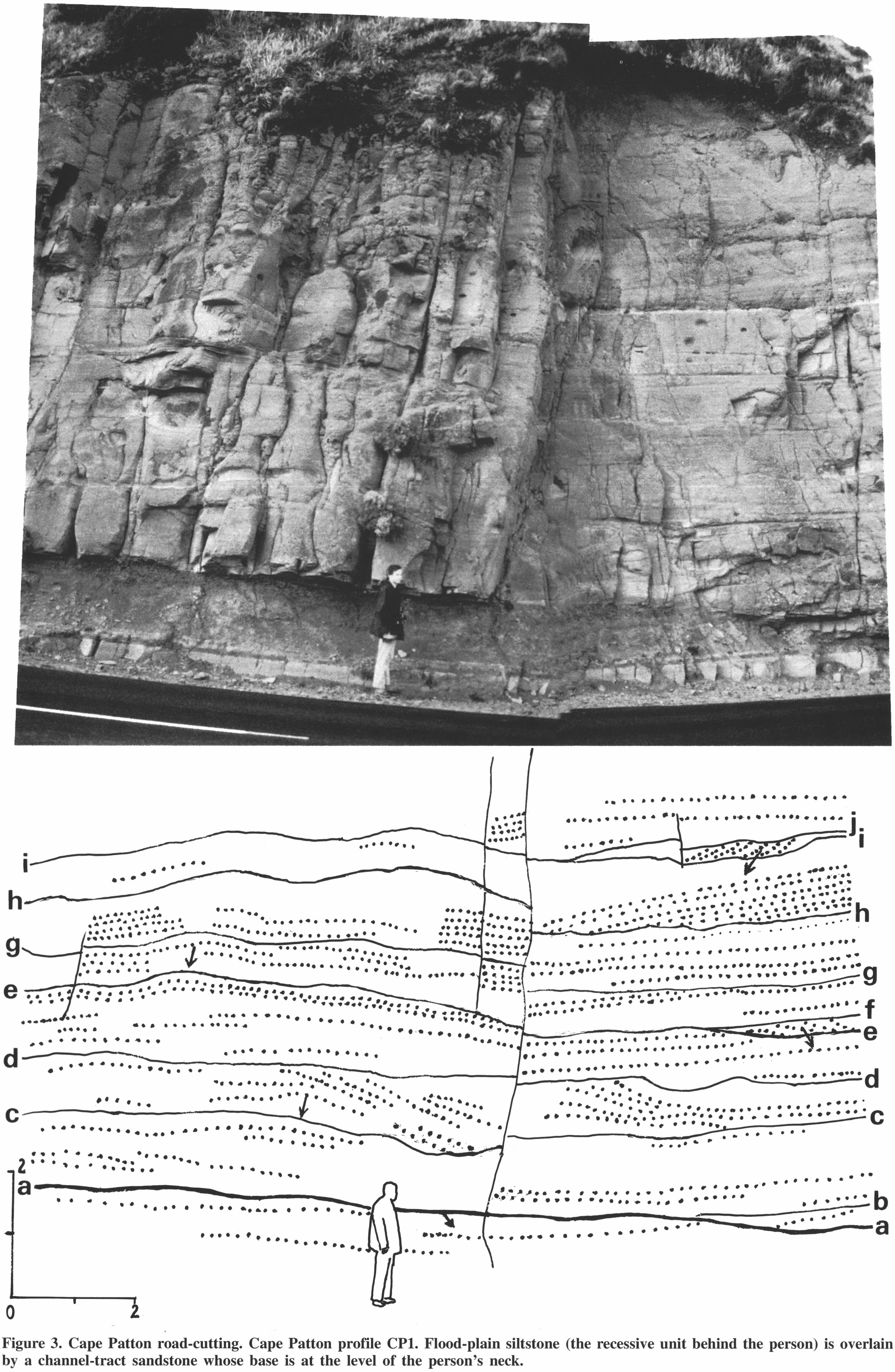

Figure 3. Cape Patton road-cutting. Cape Patton profile CP1. Flood-plain siltstone (the recessive unit behind the person) is overlain by a channel-tract sandstone whose base is at the level of the person's neck.

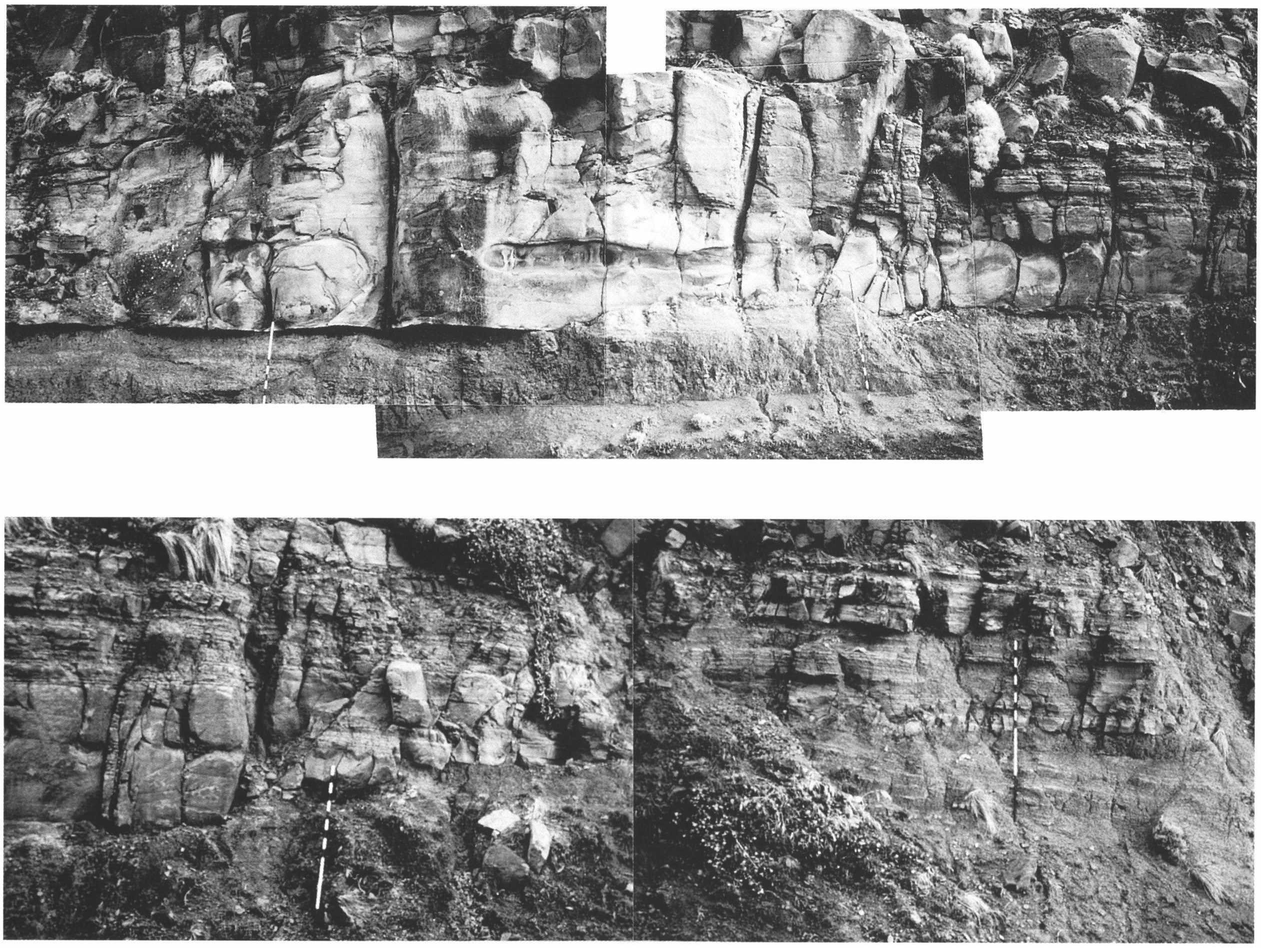

Figure 4. Cape Patton road cutting: the base of the channel-tract sandstone illustrated in and 10 m along strike to the right of Figure 3. The two photographs (a, top; b, bottom) are continuous, but are reproduced at different scales. The lowermost sandstone unit, a channel fill containing large elongate concretions (channel 1) is cut into flood-plain siltstone. It thins sharply towards its margin, and interfingers with fine-grained sedimentary rocks in a levee (right-hand side of b). Channel 1 and its levee have been partly eroded by the overlying channel 2, which also passes laterally into a levee sequence containing thin fining-upward splay sands. The levees are displaced relative to the channel-tract sandstone owing to greater compaction of the interbedded finer rocks, apparent at the right-hand side of a and in b. The staff is 2 m long, and has divisions at 50 cm and 10 cm.

preted rock bodies are presented in Table 4; thin coal and carbonaceous mudstone beds are conspicuous but minor components of some of them. Whereas abandoned channel-fills become finer-grained in vertical sequence, and their upper parts commonly consist of several fining-upwards units (e.g., Fig. 8, units 10–11), flood-plain deposits generally show no consistent grainsize trend (e.g., Fig. 14, units 1–8).

Sheet siltstone. These bodies are usually no more than 3 m in (compacted) thickness (Table 4), and are areally extensive. Thin coal and carbonaceous mudstone are conspicuous but minor components of some bodies. They represent low-energy deposition in (i) moderately flat interchannel areas inundated at high flood stages, and (ii) basin-like shallow depressions — the locations of flood-plain lakes and swamps — within those areas.

Sheet sandstone. Sheet sandstone bodies in the association are of wide lateral extent and tabular form, and have varying thicknesses up to 3 m. They usually have one storey, and are composed of few lithofacies. Most sheet sandstones have palaeocurrent directions divergent from over- and underlying channel-tract sandstones, and probably represent splay/sheet-flood deposits. Some may be distributary channelways.

Lenticular sandstone. Lenticular sandstone has a similar thickness to sheet sandstone, from which it differs mainly in lateral extent. Those bodies with erosional bases and internal cross-bedding are interpreted as flood-plain distributary channels (e.g., Rotten Point; Table 4; Fig. 6). Those which have gradational relationships with flood-plain siltstone and channel-tract sandstone are probably levee deposits (e.g., Cape Patton; Table 4; Figs. 3, 4a, 4b).

Lacustrine facies association

The lacustrine facies association is thickest and most widespread in the lower part of the Eumeralla Formation (lower Albian *C. striatus* Zone; Struckmeyer & Felton 1990), although outcrops are limited. The lacustrine facies association is exposed at Browns Creek (Fig. 14), and in cuttings along Skenes Creek Road north of Apollo Bay (figs. 11–14, part I), where much of the 270-m exposed section consists of lake-basin mudstone and siltstone. Parts of thick intervals of flood-plain facies association sediments at Blanket Bay (Table 4) may be deposits in shallow flood-plain lakes.

The lateral extent of the assocation is unknown, although parts of Eumeralla II have been correlated with this association (part I). Felton (1992) discussed evidence for a deep perennial lake origin for the thick sequences of uniform, dark silty mudstones in a water well near Apollo Bay, and in petroleum exploration wells near the northeastern margin of the Otway Basin.

This association is distinguished from fine-grained parts of the fluvial-flood-plain facies association by its general lack of sandy lithofacies, overall finer grainsize, and thickness.

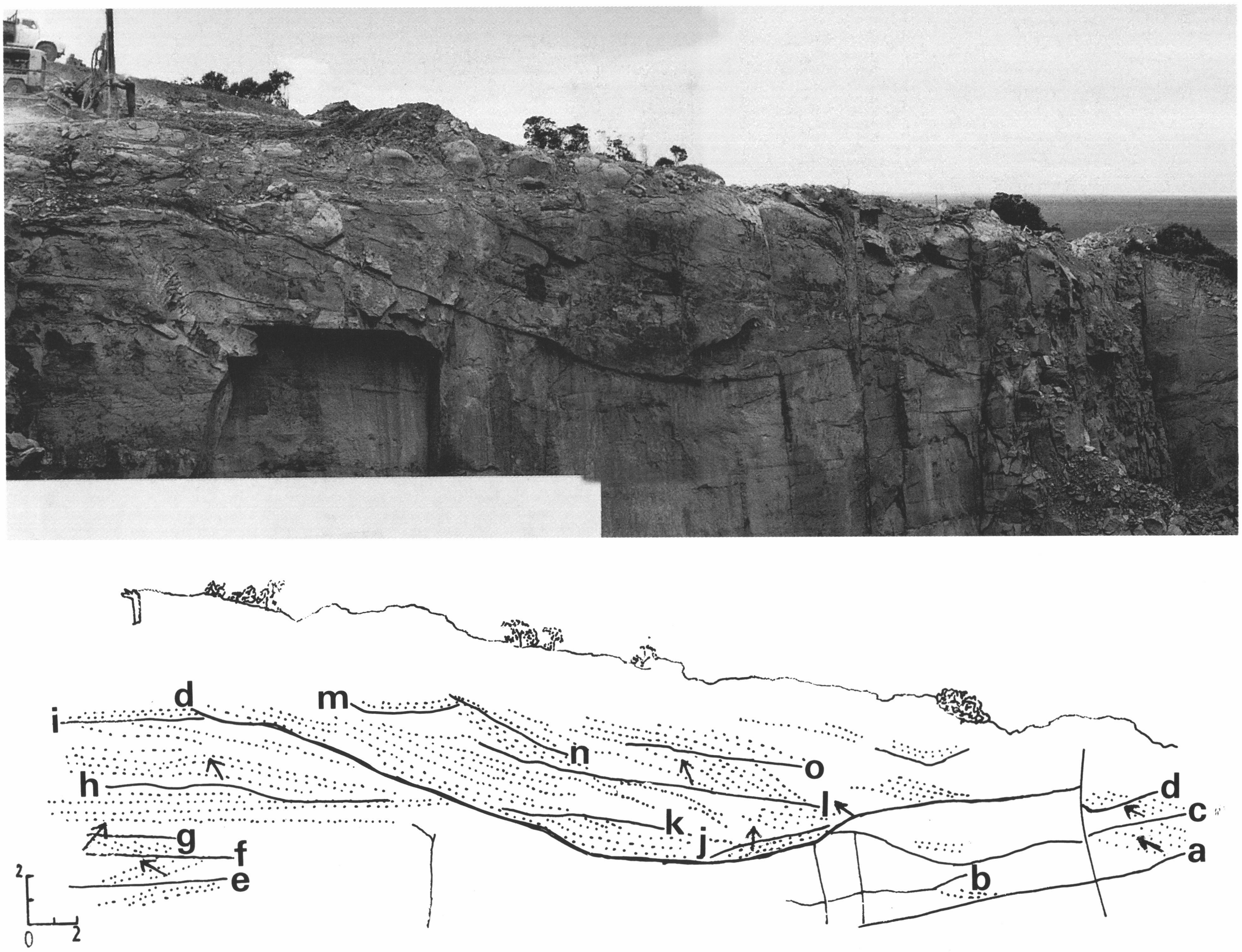

Figure 5. Holtzers Quarry profile HQ1. The person standing next to the drilling rig (upper left) provides the scale.

Distal overbank deposits — recognised by intercalations of thin fine-grained rippled and laminated sheet sandstones — interfinger with interpreted lake-margin sedimentary rocks at Browns Creek (Fig. 14).

Lacustrine deposits

Two styles of deposition, described below, are recognised in outcrop.

Lake basin. Lake-basin deposits consist mainly of finely laminated mudstone and siltstone (figs. 11–14, part I). Laminae less than 2 mm thick are distinguished by subtle colour variations that correspond to grainsize changes. Regularly alternating light and dark laminae which might suggest varves are not apparent. At the Skenes Creek Road locality, rare thin light beds with compact texture and blocky fracture may be airfall tuffs. Their origin is obscured by weathering.

Local starved ripples with amplitudes of 8 mm or less, and single ripple trains with amplitudes of 1–2 cm, consist of silt and fine sand; such ripples have commonly sunk into underlying muds. Vertical to subvertical burrows and bioturbated layers occur in places in shallow lake deposits. Macerated plant debris, now coalified, is abundant in both shallow and deeper lake-basin sediments (Struckmeyer & Felton 1990).

Lake margin. Fine- to medium-grained lithic-quartz sandstone bodies are enclosed by lake-basin sedimentary rocks as described above. Their characteristics and interpretation were discussed in detail by Felton (1992), and are summarised in Table 5. These sands mostly represent different parts of small deltas prograding into the lakes.

The interpreted lake-beach sandstone (Table 5) differs from other sandstones in lacustrine sequences in being more quartz-rich and well sorted. Internally it is well bedded; it is cross-bedded in part, and the thicknesses of individual beds do not exceed 30 cm. The cross-bedding may be low angle. This sandstone is isolated in thick lake-basin mudstone, with which it has sharp planar upper and lower contacts; if it is a lake-beach deposit, it would have accumulated at the lake margin during a rapid fluctuation in lake level.

Fluvial regime of Eumeralla rivers

Depositional processes

Bedforms

Bed mesoforms identified in outcrop are interpreted as bars of various types which formed and moved in stream channels, and were presumably stable over at least part of the prevailing flow regime (Rust & Koster 1984). Three types of bed mesoforms are recognised in the Eumeralla Formation channel tracts. Plane-bedded bars, of both simple and complex type (Allen 1983), are dominant. Dunes may occur throughout the channel tract, but sand waves are largely confined to the upper parts of channel deposits.

Plane-bedded bars. The margins of large plane-bedded bars may rarely be visible (cf. Allen 1983), depending on the scale and orientation of both outcrop and bar. In the study area, low-angle accretion surfaces at bar margins are common because the bars are generally smaller than outcrop scale (tens of metres). Both simple and complex plane-bedded bars in the Eumeralla Formation channel tracts are commonly a few metres to tens of metres long and wide, less than 1.5 m thick, and tabular, rather than elongate. The largest plane-bedded bar noted in the study area, south of Blanket Bay, was 150 m long in the downstream direction, and 4 m thick (Fig. 15); its lateral extent could not be observed.

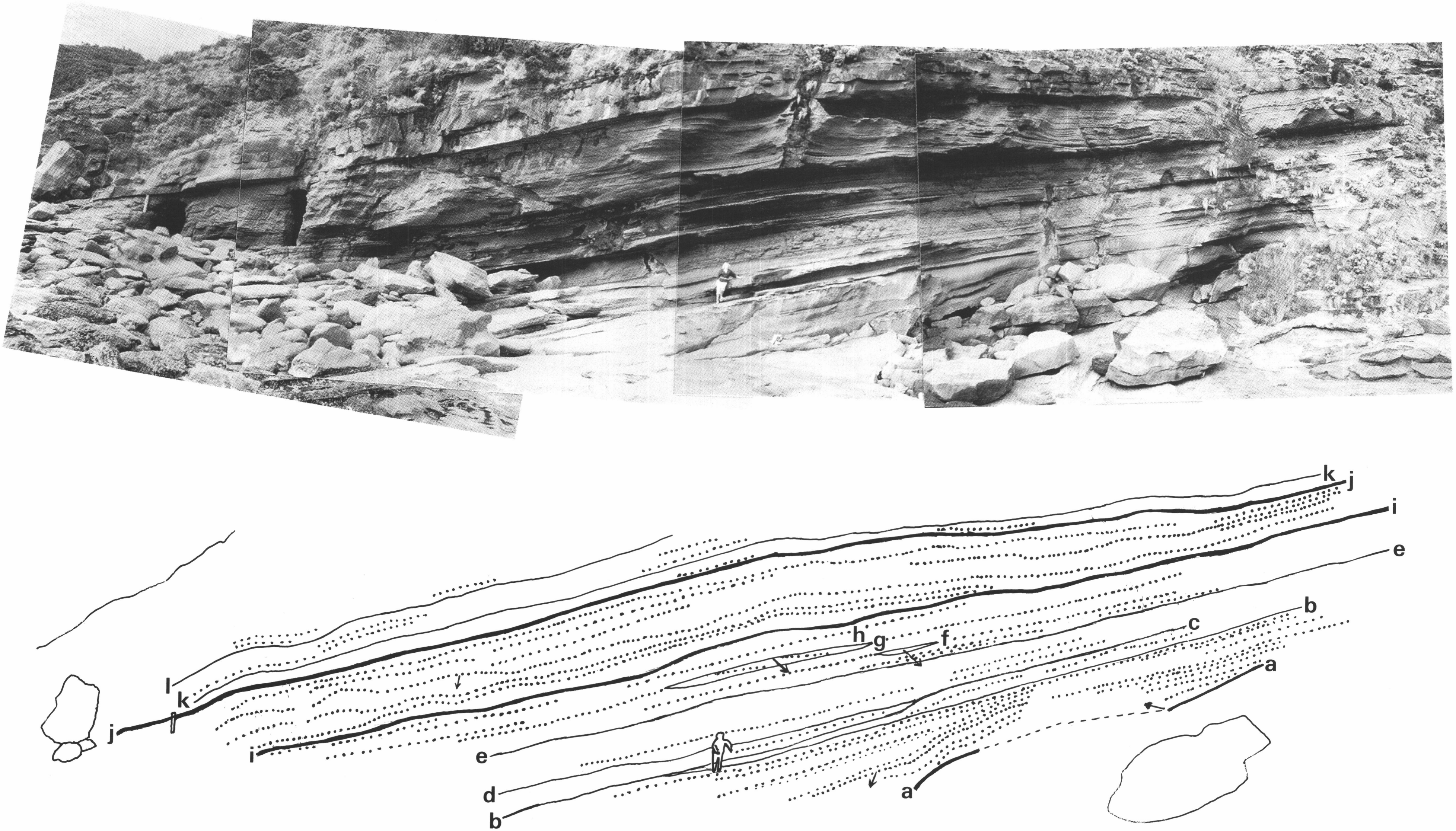

Figure 6. Rotten Point profile RP1.

Table 3. Parameters of fluvial-channel-tract sandstone bodies

Field location	*Lateral dimensions*	*Thickness (m; range observed)*	*Max. relief (m) on base*[1]
Cat Reef/Fiji Point (4 bodies)	150 m+ normal & parallel to depositional dip (all)	12–14	Flat (all)
West of Johanna Beach (1 body)	Updip extent not known; 1.5 km+ normal to depositional dip	10–15 E to W	2.5
Rotten Point (1 body)	400 m+ normal; 200 m+ parallel to depositional dip	35	Not seen in detail
Blanket Bay (1 body)	100 m+ normal & parallel to depositional dip	70	6
Marengo (1 body)	100 m+ normal & parallel to depositional dip	70+	2.5
Cape Patton (2 bodies)	150 m+ normal to depositional dip (each)	60+; 30+	6; flat

[1] All basal contacts are third- or higher-order, erosional.

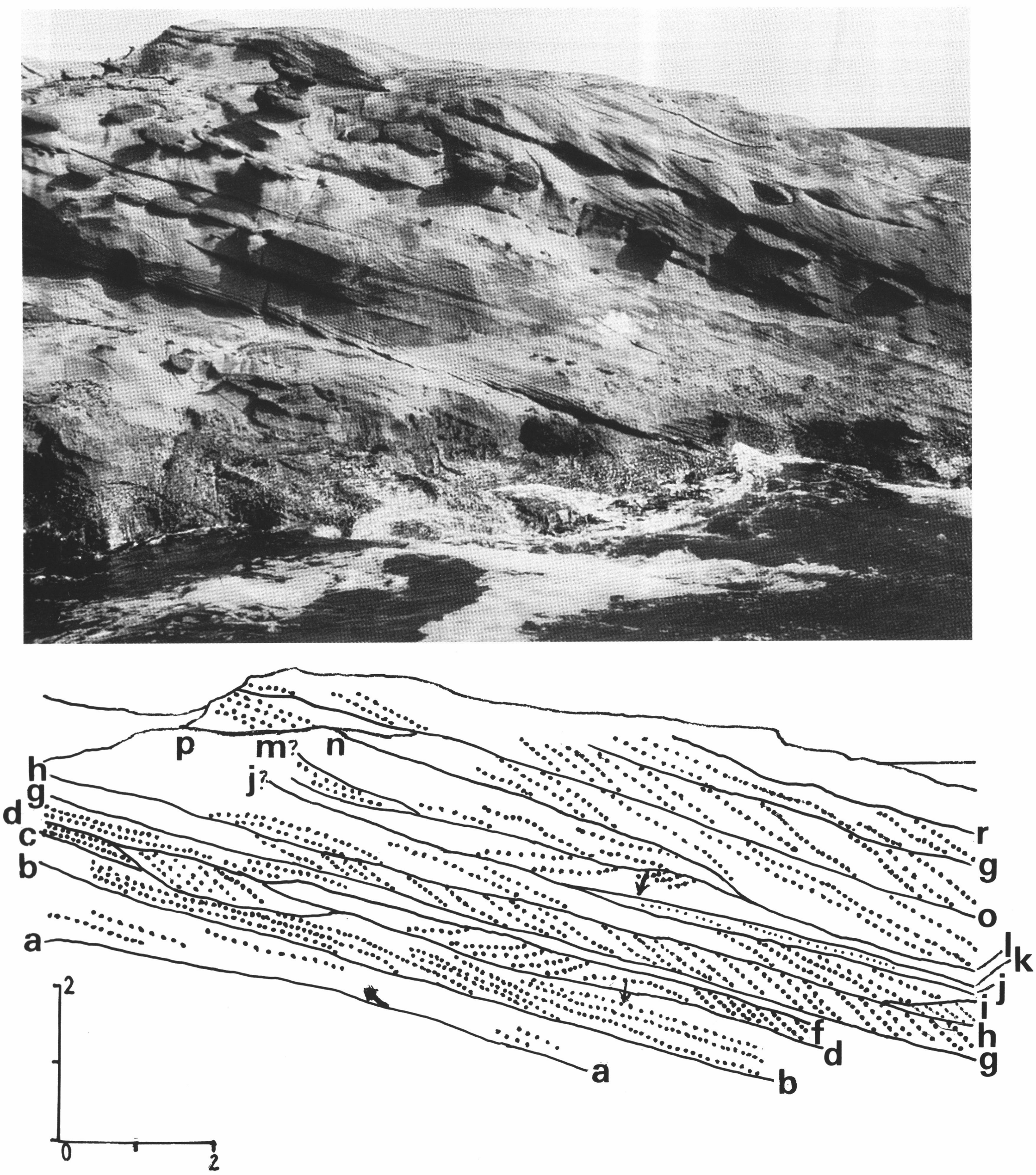

Figure 7. Rotten Point profile RP2.

Table 4. Characteristics of the flood-plain facies association

Field location	*Architectural element*	*Sedimentary structures*	*Lateral dimensions*	*Maxium thickness*	*Nature of contacts*
Cat Reef/Fiji Point (3 bodies up to14 m thick[1]; fig. 15, part I)	1. Sheet siltstone ± coal (90%)	Laminae, ripples, rootlets, bioturbation, pedogenesis	50 m+ along strike and updip	6 m	Gradational bases; sharp or erosional tops
	2. Lenticular sandstone (10%)	Trough X-beds	4 m+ updip	1 m	Erosional bases; sharp tops
West of Johanna Beach (1 body 30m thick)	1. Sheet siltstone (60%)	Laminae, ripples	1.5 km+ along strike; 150 m+ updip	3 m	Gradational base; sharp or erosional top
	2. Sheet sandstone (40%)	Trough cross-beds	As above	3 m	Sharp base; gradational top
Rotten Point (2 bodies with maximum thicknesses of 19 and 35 m; Fig. 8, units 10–13 & 15–21)	1. Sheet siltstone (70%)	Laminae, ripples, rootlets, bioturbation, pedogenesis	400 m+ along strike; 200 m+ updip	3 m	Gradational bases; sharp or erosional tops
	2. Sheet sandstone (25%)	Low-angle and trough cross-beds; plane bedding	As above	2.5 m	Sharp bases; gradational tops
	3. Lenticular sandstone (5%)	Low-angle and trough cross-beds; ripples	4 m updip	1 m	Sharp bases and tops
Blanket Bay (2 bodies 70 m and 64 m thick; Fig. 13)	1. Sheet siltstone (85%)	Laminae, ripples, bioturbation, rootlets	100 m+ updip and transverse	22 m	Gradational bases; third- or higher-order erosional tops
	2. Sheet sandstone (15%)	Ripple lamination	As above	0.5 m	Sharp bases; second- or higher-order and sharp or gradational tops
Cape Patton (1 body 30+ m thick; Figs. 3–4)	1. Sheet siltstone, minor coal	Laminae, ripples, ?rootlets, ?pedogenesis	150 m+ transverse to depositional dip	3 m+	Base grades to underlying channel tract; third- or higher-order erosional top
	2. Lenticular sandstone	Ripple and wavy laminae; thin silty interbeds	6 m down depositional dip	2 m	Gradational base; passes laterally into and overlain by channel-tract sandstone
Skenes Creek Road (1 body 10+ m thick; fig. 12, part I, units 1–7)	1. Sheet siltstone/fine sandstone ± thin coal	Laminae (internal structure obscure)	7 m+ along depositional strike	3 m	Gradational base with underlying lacustrine mudstone; erosional top
	2. Sheet sandstone	Trough cross-beds	As above	0.7 m	Erosional base; sharp or gradational top
Browns Creek (1 body 20+ m thick; Fig. 14, units 4–7)	1. Sheet siltstone/fine sandstone ± thin coal	Laminae (internal structure obscure)	700 m+ along depositional strike	2 m	Gradational base with underlying lake mudstone or distributary-channel sandstone; erosional top
	2. Sheet sandstone	Trough cross-beds	Several hundred metres along depositional strike	1 m	Erosional base; gradational top

[1] All bodies of the flood-plain facies association are gradational, underlie channel tracts, and have third- or higher-order erosional upper contacts.

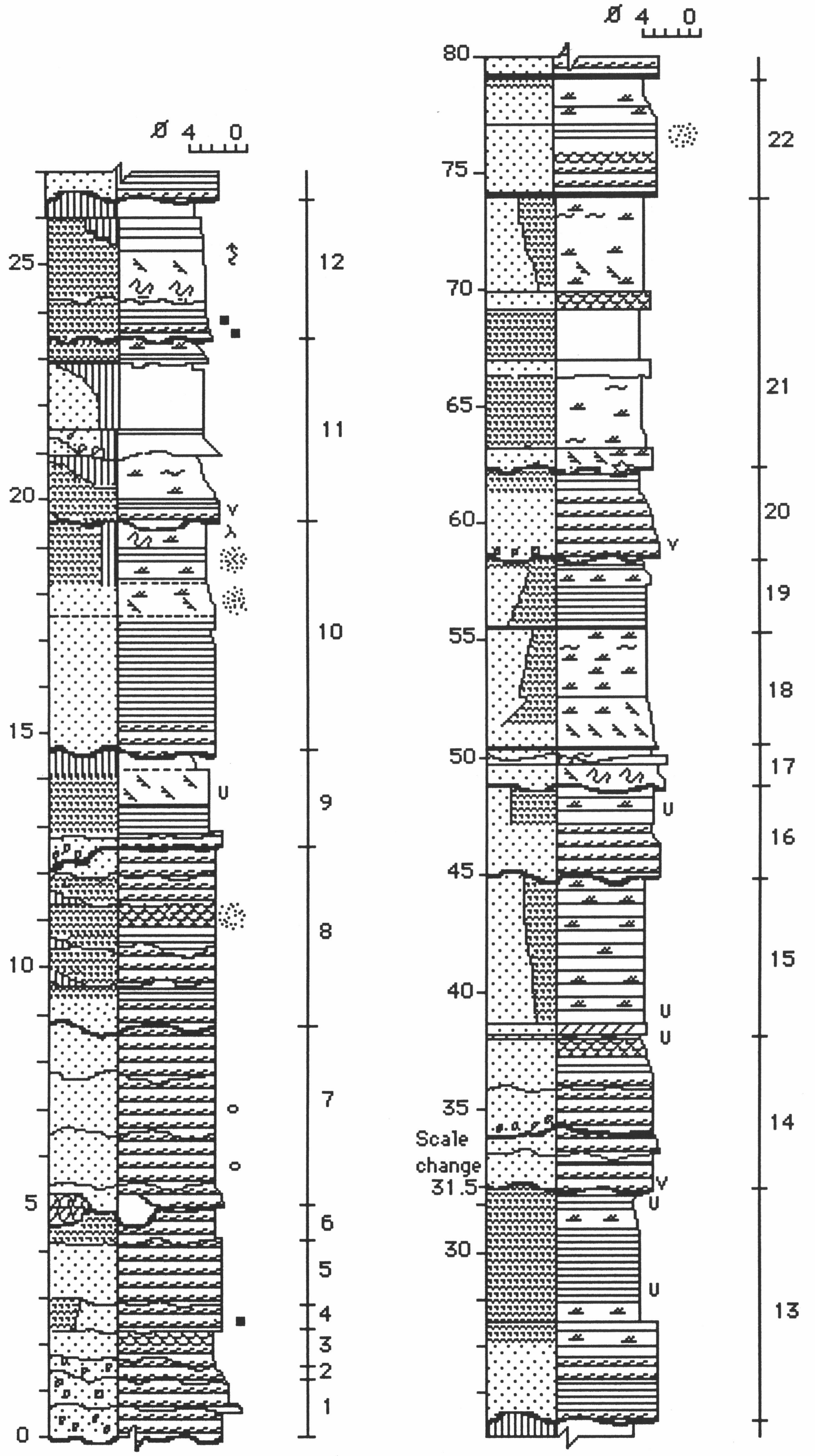

Figure 8. Rotten Point profile RP3.

Table 5. Parameters of lake-margin sandstones

Sandstone body	*Thickness (m)*	*Base*	*Top*	*Facies*	*Overlain by*	*Interpretation*
Browns Creek, tops of units 1, 2 (Fig. 13)	0.75–1	Gradational; coarsens upward	Gradational; fines upward	Sr, Src	Fm, Fl	Distributary mouth bar succeeded by lake basin
Skenes Ck Rd, unit 4 (fig. 11, pt I)	0.4	Gradational; coarsens upward	Sharp, planar	Sr	Fm, C	Distributary mouth bar succeeded by infill marsh
Browns Creek, near top of unit 3 (Fig. 14)	0.5	Gradational; coarsens upward	Sharp, planar	Fl	Fl	As above; partly eroded by distributary channel
Skenes Ck Rd, unit 2, (fig. 11, pt I)	0.3	Gradational; coarsens upward	Sharp, planar	Sh, Sr	Fm, Sr	Mouth bar succeeded by levee
Skenes Ck Rd	1.8	Sharp, planar	Sharp, planar	Sl, ?Sp	Fm, Fl	Lake beach succeeded by lake basin

Internal bedding in the marginal parts of plane-bedded bars in the Eumeralla Formation commonly has low-angle relationships with underlying surfaces. Further, the low-angle bedding on the bar margins commonly is highly differentiated in grainsize, bed thickness, and internal structure (Figs. 9, 10).

Bar formation was probably initiated on fairly flat stream beds which developed after an initial cut-and-fill episode associated with the onset of flooding. The mechanism of bar initiation may have been similar to that suggested by Leopold & Wolman (1957): longitudinal bars nucleate about small accumulations of the coarsest bedload fractions, deposited as flow decreases; they grow mainly in the downstream direction by the addition of material to their downstream ends. This process in Eumeralla rivers permitted local bed aggradation and bar growth, and the concomitant development of low relief in the stream bed. Flow separation induced by relief in the bed, which — in conditions of falling-stage flow — would normally result in the formation of lower-flow-stage dunes and sand waves, was suppressed as high-stage flows continued. Weak separation eddies prevailed locally, as did flow fluctuations, inducing sediment deposition on the downstream and lateral margins of the bars. Low-angle accretion surfaces thus developed at high angles to the palaeoflow.

The high variances observed in measurements of current directional indicators in the mainly upper-stage-flow Eumeralla rivers (Felton 1992) are consistent with the model for sediment deposition and bar growth discussed above. The bi-directional trends observed in many palaeocurrent roses (Fig. 16) lend support to the suggestion that much of the sediment accumulated on the sides of plane-bedded bars.

Plane-bedded bars and bar complexes formed at the high-fluvial-flow stage were modified during falling- and low-flow stages (cf. Smith 1971). Modifications observed in this study include erosion of the sides of bars; channelling-in and erosion of their tops; and deposition of reworked sediment in low-stage channels surrounding the bar complexes. Repeated cut-and-fill, reactivation surfaces, abundant intraclasts strewn along those surfaces, and rare in-situ fine-grained sediments all attest to considerable fluctuation of flow stage in Eumeralla III fluvial-channel tracts.

Dunes. Trough cross-beds are developed throughout the channel-tract sandstone. Where they occur near storey bases in multistorey sandstones, they represent dunes which formed and moved on channel floors after the initial scouring of a channel during the rising stages of floods.

Small trough and planar tabular cross-bed sets in places are interbedded with finer sediments at the tops and sides of plane-bed cosets; they are usually isolated single sets, or consist of two to three sets separated by reactivation surfaces. They developed as flow fluctuated over the tops of bars in the stream channel. They also formed in response to waning flow at the tops of channel-tract sandstones as the tract was abandoned.

Sand waves. Sand waves, or planar tabular cross-bedded bars, are uncommon in the Eumeralla Formation. Small planar tabular cross-sets (30 cm thick) in places formed above or lateral to plane-bedded bars, an indication that local decreases in current velocity occurred around larger bars.

Larger planar tabular sets and cosets, up to 2 m thick, are best developed at Fiji Point, where they overlie mainly plane-bedded sandstone. They represent simple bars or sand waves. They record not only a lower flow regime in the channel tract, possibly resulting from loss of flow competence in wider, shallower channels, but also current directions divergent from the vector mean of palaeocurrent directional indicators in the area (Felton 1992, appendix 4A). An inspection of Walker & Cant's (1984) illustration of the morphology of simple bars indicates that measurements of these bedforms, whose downstream side may consist of one or more arcuate lobes, may diverge from the direction of palaeoslope by up to 180°.

Fluvial style

Eumeralla river systems were dominated by high-stage flow. The small scale and general lack of sedimentary features formed under lower flow regimes attests to rapidly rising and falling flows that were not conducive either to the formation or preservation of such features. Scour channels probably formed during the rising and peak stages of floods, when nearly all sediment was entrained. At peak flood stage, the sediment-charged water overtopped the banks of deep scour channels to spread out laterally as upper-flow-regime sheet floods. The ensuing drop in flow competence in the channels enhanced in-channel sediment aggradation as channel-floor dunes [facies St, low-angle cross-beds (Ss), and small-scale plane-bedded bars (Sh/Sl)]. Elsewhere in the channel tract, sediments were deposited mainly as plane-bedded bars (Sh/Sl) as high-stage flows continued after peak flood. These bars prograded laterally into the scour channels, and merged with the in-channel deposits. The resulting channel tracts were broad and moderately flat, and lacked well-defined margins.

Palaeohydrology

Water depths

According to the method of Allen (1984), water depths of 2 to 6 m are estimated from trough cross-beds in secondary and tertiary channels near the tops of channel-tract sandstone bodies at Fiji Point. The mean measured thickness of the trough cross-beds here is 40 cm, to which is added 25 per cent to yield an estimate of the group mean for the original dune heights (50 cm). Water depths estimated by this method

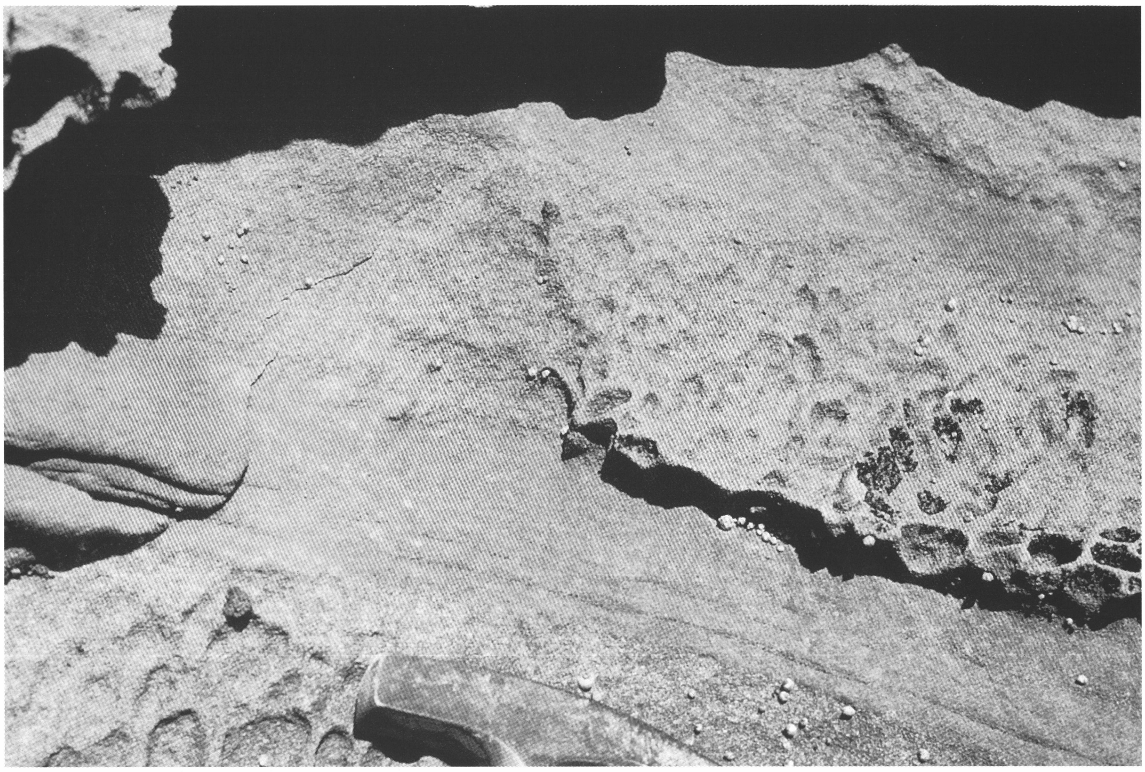

Figure 9. Rotten Point profile RP3, unit 4: detail of facies Sl. Thickened beds near the base of a low-angle cross-bedded bar consist of fine and coarse-grained sandstone, both of which are internally laminated.

Figure 10. Rotten Point profile RP3, unit 4: detail of facies Sl. A thickened bed consists of climbing-ripple muddy fine-grained sandstone with mud flasers; the basal contact of the overlying coarse sandstone is load-casted into the finer unit. The light-coloured pebbles are muddy siltstone intraclasts.

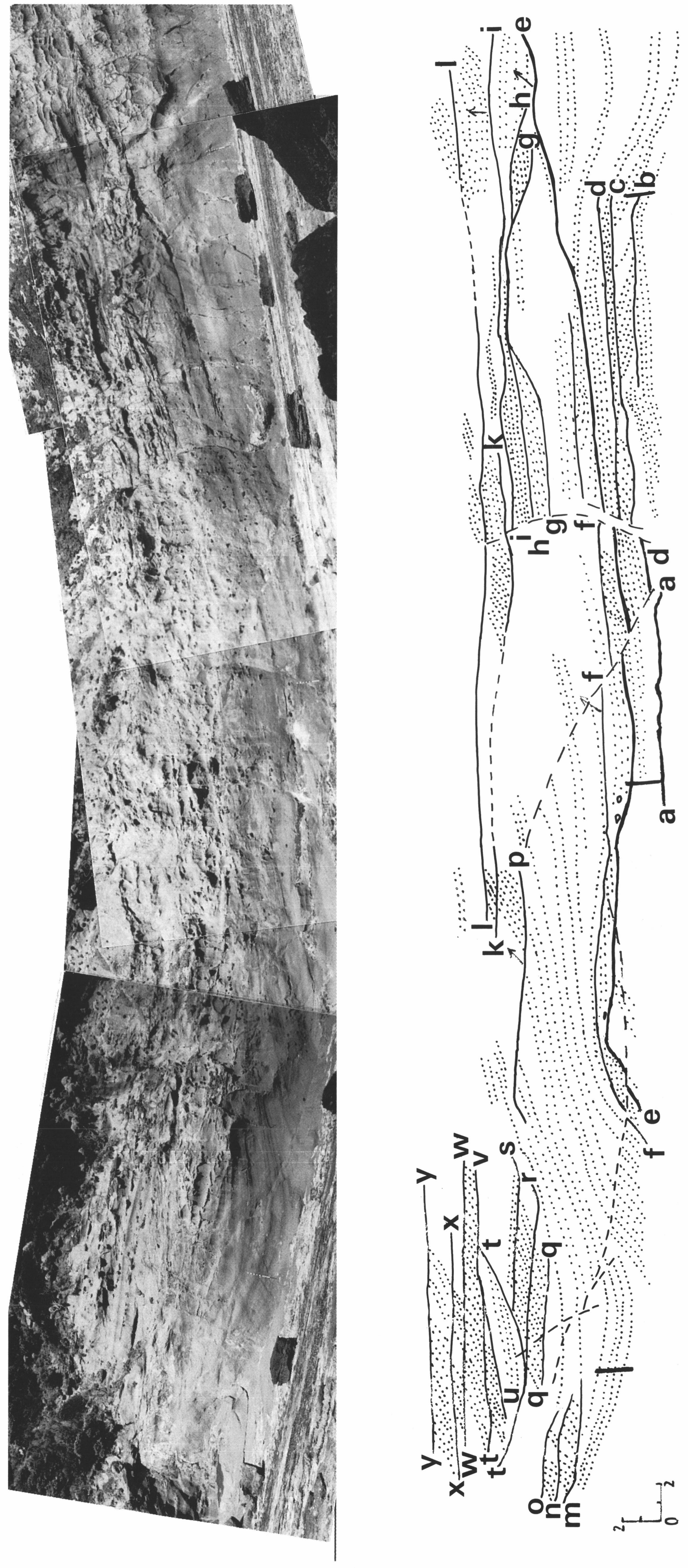

Figure 11. Cat Reef profile CR2. The measuring staff is 2 m long.

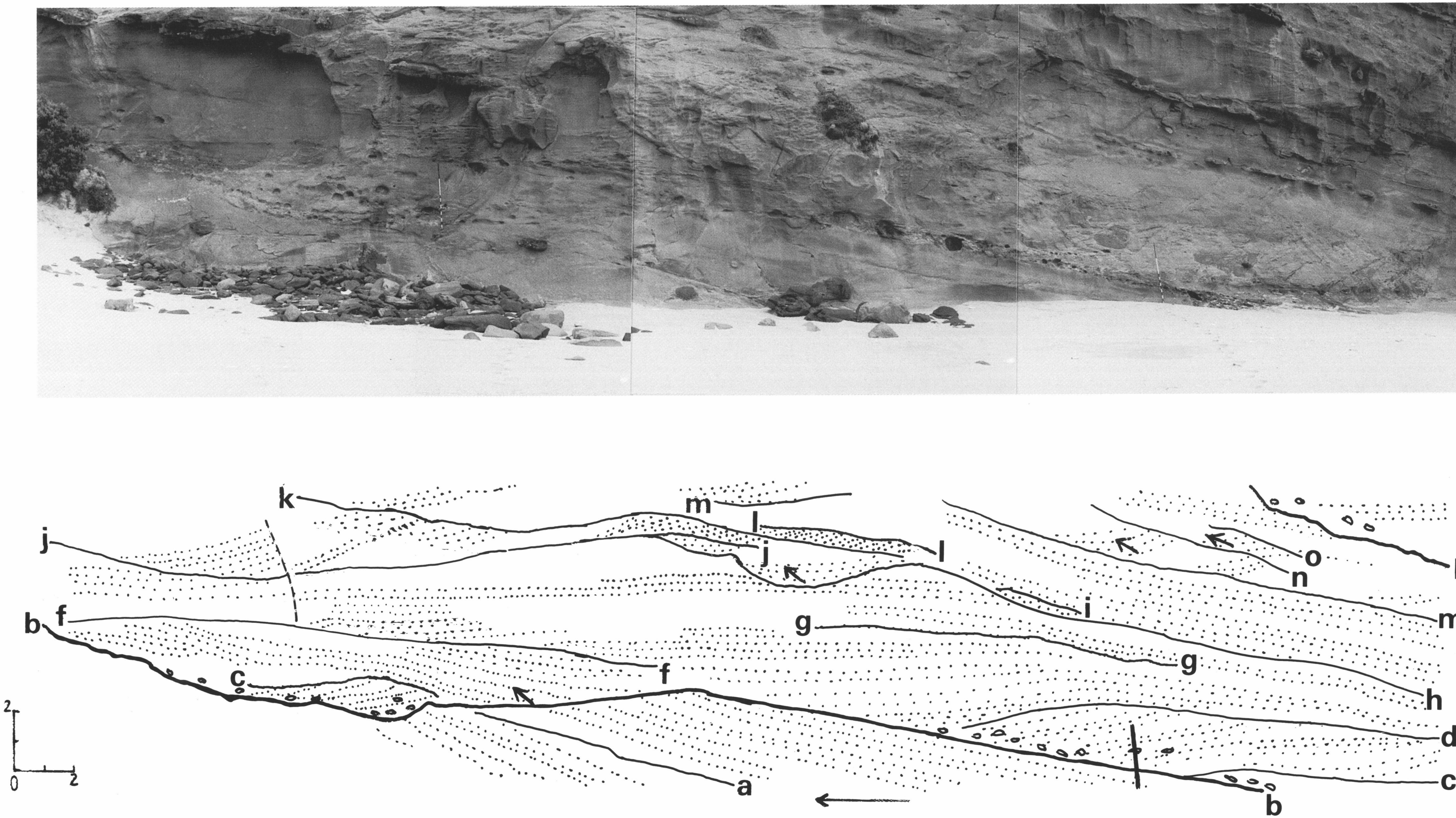

Figure 12. Johanna Beach profile JB1. The measuring staff (with 0.5- and 0.1-m graduations) is 2 m long.

are similar to channel depths estimated from the maximum preserved thickness of filled channel forms at nearby Cat Reef.

The bank-full depths of Eumeralla streams are not less than the depths of the major scours and the maximum thicknesses of bars (cf. Allen 1983). Scour depths range from 2–6 m at Blanket Bay and Marengo, and 2–4 m elsewhere (Table 6). Maximum preserved thicknesses of bars are 5 and 4 m respectively (Table 6); however, the mean height of plane-bedded bars, rarely more than 1 m, indicates a minimum depth of water in channels during bar formation as 1 m.

Slopes, sinuosities, and discharges

From determinations of the silt/clay percentages of bank and channel material, and channel width:depth ratios, in modern fluvial systems, Schumm (1960, 1972) developed methodologies for estimating discharges in straight reaches of stable alluvial channels. These methods are designated I and II respectively in the discussion which follows.

Schumm's equations may have limited application to Eumeralla rivers, whose channels were probably not stable although they probably had straight reaches. Also, Eumeralla channel forms are rarely preserved, so estimates of slope, sinuosity, and discharge based on parameters associated with them will be representative of only small parts of the fluvial system(s). Despite the limited data, internal comparisons of different parts of the system(s) are possible (Table 7).

Blanket Bay channel. The Blanket Bay channel is a moderately deep sand-and-gravel-filled scour cut into medium-grained volcaniclastic sandstone containing about 10 per cent coarse quartzose sand. It was probably cut during the rising stage of a flood. If its margins were eroded at peak flood, the estimates of its dimensions, especially width, might be too low. Percentages of silt and clay (method I), difficult to determine accurately in weathered rock, were estimated for the stream bed and bank (Table 7). Method II is preferred for calculations associated with this channel.

The estimated width:depth ratio according to method II is low, and may reflect the greater power of gravel-charged fluvial flows to cut deeper channels, or the preservation of only the deepest part of a larger channel. Sinuosity, slope, mean annual discharge, and bedload are all similar to the Cat Reef channels (Table 7). A calculated average sinuosity of 1.5 is similar to that of sandy mixed-load streams of braided or meandering character (e.g., Schumm 1972).

Cat Reef channels. These two channel forms (Table 7) are incised into older sandy deposits (Fig. 11). At least one of the margins of each of the channels is eroded. As a result, the estimates of channel widths are low, and consequently so too are the method II calculations of width:depth ratios, the lowest for any of the channels examined in this study. Despite the difficulty of determining bank and channel silt/clay percentages in weathered rocks, method I is preferred over method II owing to the uncertainty of the original widths and depths of these channels.

The estimated width:depth ratios for the two channels according to method I are intermediate between the ratios estimated by method II for the Blanket Bay and Cape Patton channels.

Cape Patton channel. The Cape Patton channel, overlying and incised into flood-plain siltstone (Figs. 4a, 4b), is probably the most completely preserved of the four channels studied, and — having silty banks — was the most stable. Both margins of the Cape Patton channel (channel 1 in Figs. 4a, 4b) are exposed in a road-cutting oriented normal to palaeoflow; a

Table 6. Comparison of Eumeralla depositional systems

	Depositional system A	*Older depositional system B*	*Depositional system B*	*Depositional system C*
Outcrops	NE of Cape Otway, SW of Apollo Bay	NW of Cape Otway (Rotten Point–Johanna Beach)	NW of Cape Otway (Cat Reef–Fiji Point)	NE of Apollo Bay
Age	Early Albian *(C. striatus Zone)*	Early Albian *(C. striatus Zone)*	Late Albian *(C. paradoxa–P. pannosus* Zones)	Early–late Albian *C. striatus, C. paradoxa*, and *?P. pannosus* Zones
Sediment composition	Volcaniclastic sand (2 Ø), granitic detritus (–1 Ø), metamorphic pebbles	Volcaniclastic sand (1–2 Ø)	Volcaniclastic sand (1 Ø), glassy volcanic pebbles	Volcaniclastic sand (2 Ø), minor granitic metamorphic pebbles and metamorphic detritus (–1 Ø) including pebbles
Character of channel tracts:				
Floor	Scours to 6 m	Scours to 2.5 m	Scours to 2.5 m, channel forms	Scours to 2.5 m, channel forms
Fill	Plane-bedded bars to 5 m thick; channel-tract sandstones to 70 m thick	Plane-bedded bars to 3 m thick; channel-tract sandstones to 40 m thick	Plane-bedded bars to 2 m thick; planar tabular cross-channel bars to 2 m thick; channel-tract sandstones to 14 m thick	Plane-bedded bars to 3 m thick; channel-tract sandstones >50 m thick
Character of flood plain (interchannel):				
Max. observed thickness	70 m	30 m	14 m	15 m
Lateral extent	?100s of metres	?100s to 1000s metres	?100s to 1000s metres	
Palaeoslope	S or N to NW	SE to NE	NE	

Table 7. Slopes, sinuosities, and discharges calculated from palaeochannel data[1]

Location and method	*Uncorrected width/stream width (m)*	*Uncorrected depth/stream depth (m)*	*% silt and clay in bank*	*% silt and clay in bed*	*Calculated width: depth ratio [range]*	*Estimated sinuosity [range]*	*Mean annual discharge ($m^3 s^{-1}$) [range]*	*Mean annual flood ($m^3 s^{-1}$) [range]*	*Slope [range]*	*Meander wavelength (m) [range]*	*Estimated radius of curvature (m)*	*% total load as bedload*
Blanket Bay												
Method I			10.0	5.0	41.3 [16.7–101.8]	1.43 [1.09–1.88]	37.79 [20.09–71.08]	358.55 [199.40–644.68]	0.00060 [0.00030–0.00118]	1910.67 [928.08–3933.57]	243.0	10.1
Method II[2]	**60.0/90.0**	**6.0/3.9**	**N/A**	**N/A**	**23.08**	**1.50** [1.14–1.97]	**45.61** [18.49–112.47]	**407.40** [165.21–1004.67]	**0.00043** [0.00021–0.00088]	**1466.32** [568.37–3782.94]	**429.2**	**–**
Cat Reef channel 1												
Method I			**5.0**	**5.0**	**44.8** [18.2–110.6]	**1.41** [1.07–1.84]	**34.93** [18.57–65.70]	**341.42** [189.88–613.88]	**0.00063** [0.00032–0.00125]	**1968.88** [956.35–4053.39]	**243.0**	**11.0**
Method II	60.0/90.0	10.0/6.5	N/A	N/A	13.85	1.72 [1.31–2.26]	81.23 [32.94–200.32]	570.75 [231.44–1407.49]	0.00026 [0.00013–0.00054]	1118.53 [433.56–2885.68]	429.2	–
channel 2												
Method I		**As for Channel 1**										
Method II	55.0/82.5	8.0/5.2			15.87	1.66 [1.27–2.18]	56.37 [22.86–139.03]	455.49 [184.70–1123.25]	0.00032 [0.00016–0.00067]	1132.16 [438.84–2920.85]	390.0	–
Cape Patton												
Method I			10.0	30.0	20.28 [8.22–50.01]	1.69 [1.29–2.21]	460.06 [244.58–865.40]	1802.39 [1002.42–3240.77]	0.00020 [0.00011–0.00041]	2746.55 [1334.10–5654.41]	486.0	5.28
Method II	**120.0/180.0**	**3.0/2.0**	N/A	N/A	**92.31**	**1.03** [0.79–1.35]	**51.31** [20.81–126.54]	**481.14** [195.11–1186.51]	**0.00081** [0.00039–0.0017]	**4932.09** [1911.75–12724.23]	**919.9**	**–**

[1] Correction for compaction of all channel-fill sandstones was estimated to be 10 per cent, and added to the measured depth of all channels.

[2] The preferred method and parameters calculated from it for each palaeochannel are emboldened.

levee is apparent at its right-hand margin (Fig. 4b). A second channel (channel 2 in Figs. 4a, 4b) partly eroded the initial incised channel; only one of its margins, adjacent to its levee, was exposed.

Owing to the erosion of channel 1, both its width and depth are underestimated; however, the exposed channel is wide, and any errors introduced into the determination of its parameters are probably less significant than for the narrower eroded channel at Blanket Bay. For this reason, calculations based on the Cape Patton channel width:depth data (method II;

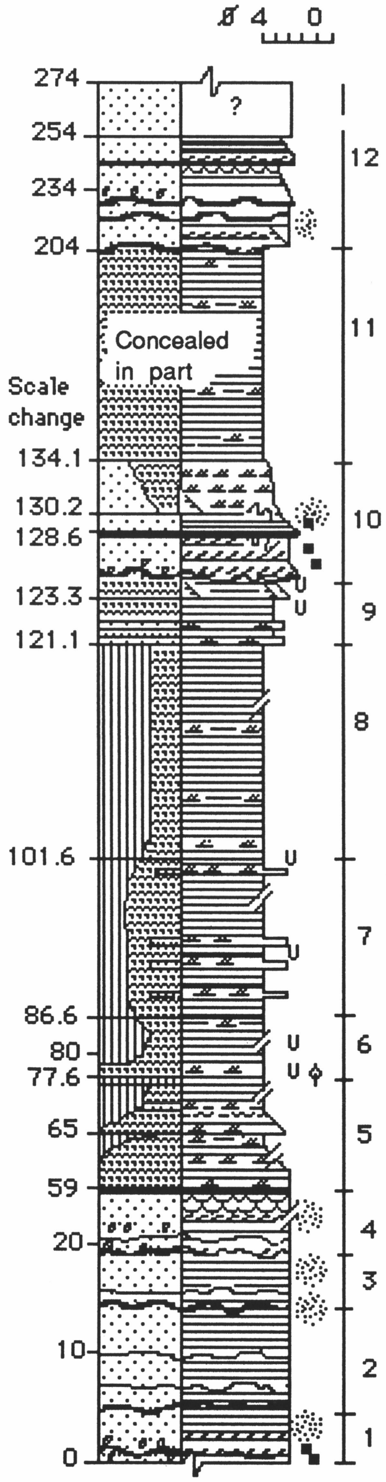

Figure 13. Blanket Bay profile BB1.

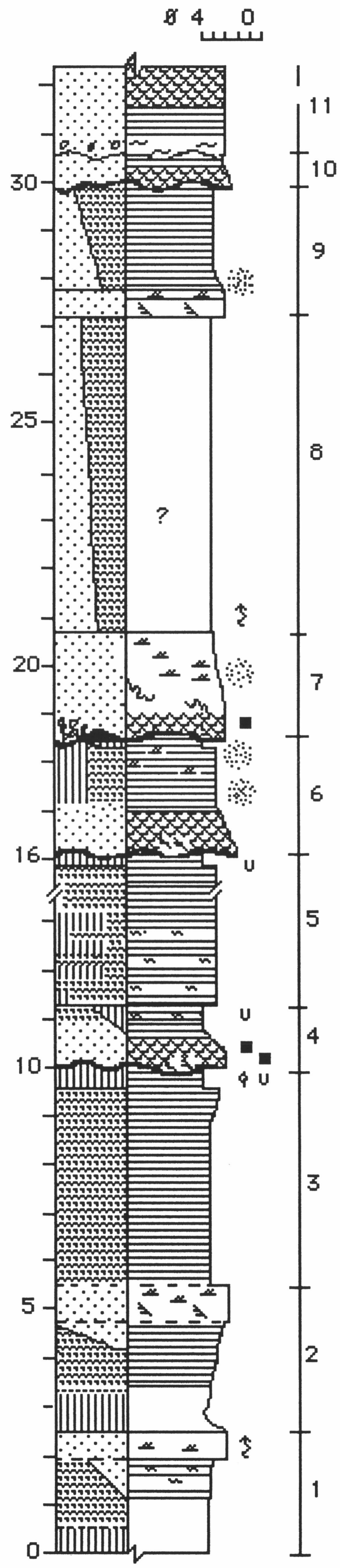

Figure 14. Browns Creek profile BC1.

Table 7) probably give the best estimates of parameters associated with Eumeralla rivers; even so, there is still considerable uncertainty in these estimates.

The Cape Patton channel has a much greater calculated width:depth ratio (92:1) than any other Eumeralla fluvial channel. It also has the lowest calculated average sinuosity and the highest calculated slope, mean annual discharge, and mean annual flood of any channel investigated.

Discussion. Even the upper limits of calculated width:depth ratios for Eumeralla stream channels (Table 7) are much less than the reported width:depth ratios of channels in sandy braided stream systems (around 200:1; Smith 1971; Cant & Walker 1976). However, the systems in these published studies have stable channels, are dominated by lower-flow-regime deposition, and are unlike the Eumeralla system(s). Eumeralla scour channels cut by rising floods are probably narrower and deeper than channels in these systems.

Calculated mean annual discharges are almost meaningless in fluvial systems for which discharge is highly variable or 'flashy'. The 'mean annual flood' would not approximate maximum discharge in an unconfined system, but may be a reasonable estimate of the discharge associated with channel cutting and scouring, before a flood peak. Calculated bedloads are low, consistent with sandy systems dominated by high-stage flow, in which most sand and all finer material would be entrained in a turbulent flow.

Regional palaeocurrents

Measured current directional features include sedimentary structures (filled channel forms, trough and planar tabular cross-bedding, and ripple and climbing-ripple cross-lamination marks) and linear features (sand-filled flutes and coalified logs on bedding planes). The vector trends reported here are based on two-dimensional vectorial analysis of data according to the method of Jones (1970), which corrects the data for structural dip — provided that the strata were not rotated during deformation. Felton (1992) presented a detailed statistical analysis of the data.

Vector means of large numbers of measurements of palaeocurrent directional data from channel-tract sandstone are considered best to approximate regional palaeoslopes, as large eddies may cause current movements on flood plains to vary considerably from the regional downslope direction (cf. Popov & Gavrin 1970). Dispersion (variance) of the directional data from Eumeralla channel tracts is high (Felton 1992), so vector means calculated from small numbers of measurements are much less reliable than those calculated from larger numbers, and might approach random distribution. Palaeocurrent roses incorporating the vector ranges and means of measurements are plotted in Figure 16. The data define four broad groups based on geographic location, age, and vector mean in channel-tract sandstone (Table 8).

In the Otway Ranges, three major palaeocurrent trends are apparent. Southwest of Apollo Bay, the trend is southeasterly to southwesterly; a southeasterly trend is also apparent at Rotten Point (Fig. 16). Northeast of Apollo Bay, a northwesterly trend is dominant, a direction also reported by Medwell (1977, 1988). In almost all these areas, the age of the rocks is early Albian (Wagstaff & McEwen Mason 1989). The northwesterly trend at Godfreys Creek is apparently in younger strata. An overall northerly trend, with variations from northwesterly at Red Johanna locality to northeasterly at Fiji Point, is apparent in younger (*P. pannosus* Zone) strata near Moonlight Head. Deep, northeasterly trending scour channels at Cat Reef, formed during the initial stages of major floods, are likely to be oriented parallel to the regional palaeoslope, and support the northeasterly trend at nearby Fiji Point.

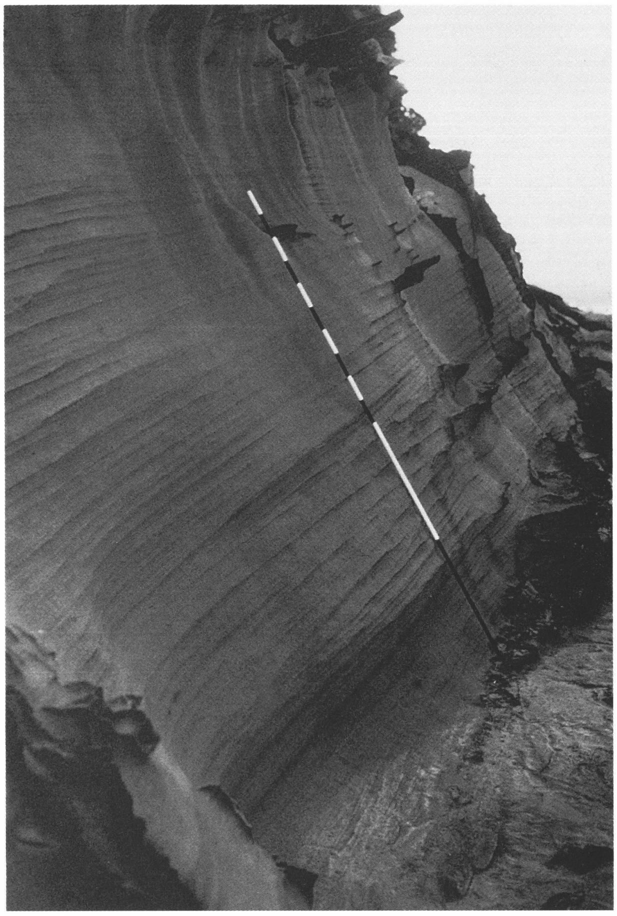

Figure 15. Blanket Bay locality. Part of a wind-eroded single set of plane-bedded sandstone, 150 m long and 4 m thick, representing a large plane-bedded simple bar. Note the carbonate-cemented siltstone intraclast stringer conglomerate (facies Gs) at the base of the bar. Elongate concretions are oriented parallel to bedding in the bar. The measuring staff (with 0.5- and 0.1-m graduations) is 2 m long.

Depositional systems

At least three discrete fluvial systems, A–C, can be recognised in the outcropping Eumeralla Formation in the eastern Otway Basin. They are distinguished by their ages, sandstone compositions, palaeocurrent directions, and dimensions of the fluvial-channel-tract and flood-plain deposits (Table 8).

Depositional system A

Marengo and Blanket Bay areas

Deposits of system A are exposed along the coast between Cape Otway and Apollo Bay (Fig. 1). System A may have evolved from an earlier fluviolacustrine system (Fig. 17) whose remnants crop out immediately north of Apollo Bay; J. Douglas (Geological Survey of Victoria, personal communication 1986) suggested that the palaeoflora in this area represent an older assemblage of his macrofloral zone C (Douglas 1969, 1986).

Although gravels are present, they are a minor part (<10%) of the observed outcrops. Roughly equal amounts of sandstone and siltstone/mudstone make up the remainder of the sedimentary section, although particles of quartz grit and weathered feldspar are common in the sandstone. A substantial part (>30%) of the framework grains in the sandstone is fine to medium epiclastic volcanic sand, whose source area is conjectural.

Mixed sandy and gravelly detritus from both basement and volcanic sources was deposited in stream channels, at least

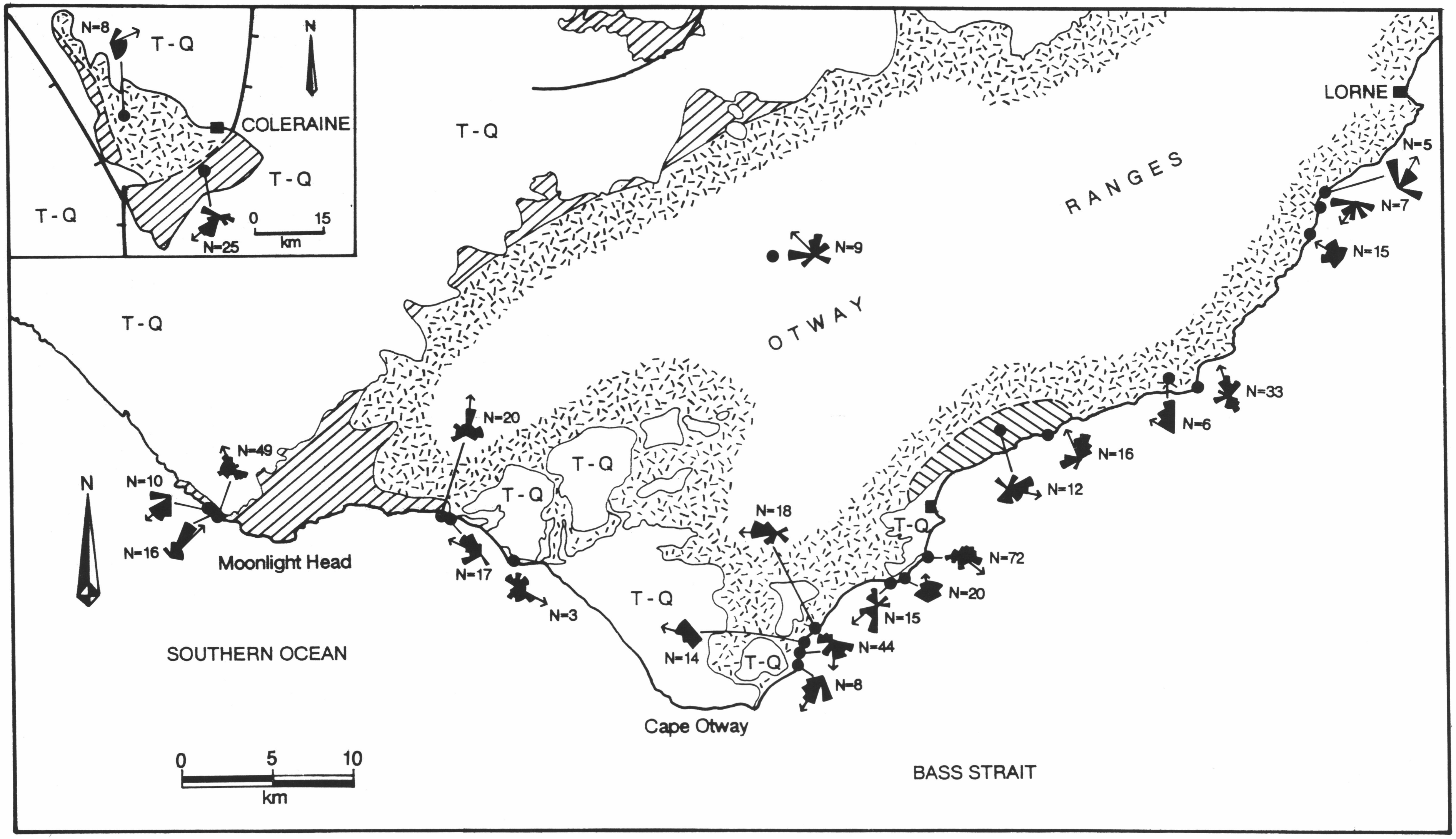

Figure 16. Palaeocurrent data for outcrops in the Otway Ranges and western Victoria.

Table 8. Summary of palaeocurrent data, Otway Group outcrops

Area	*Microfloral/ macrofloral zone*	*Vector mean(°)*	*Direction*	*Facies association*	*Depositional system*
Southwest of Apollo Bay					
Marengo	*C.* striatus[1]	127.46	S	Channel tract	A
Blowhole	*C. striatus*[2]	5.22	N	Channel tract	A
		239.21	SW		
Blanket Bay	*C.* striatus[1]	275.70	W	Channel tract	A
		284.34	WNW		
		178.67	S		
		211.32	SSW		
Northeast of Apollo Bay					
Skenes Ck Rd	'lowest zone C'[3]	105.73	ESE	Lacustrine	?A
Browns Creek	'lowest zone C'[3]	333.01	NW	Flood plain/ lacustrine	?A
Cape Patton	*C. striatus*[2]	342.17	NW	Channel tract	C
Holtzers Quarry	*C. striatus*[4]	300.30	NW	Channel tract	C
Beech Forest Quarry	*Speciosus* assemblage[5]	319.17	NW	Channel tract	C
Godfreys Creek	?*P. pannosus*[2]	299.28	NW	Channel (abandonment)	C
Artillery Rocks	*Speciosus* assemblage[5]	212.65 26.73	SSW NNE	Channel tract	C
Near Rotten Point					
Rotten Point	*C. striatus*[1, 2]	115.62	SE	Channel tract	B
Moonlight Head					
Johanna Beach	*C. paradoxa*[2]	7.48	N	Channel tract	B
Red Johanna	*C. paradoxa*[2]	296.28	NW	Channel tract	B
Cat Reef	*P. pannosus*[2]; zone D[6]	339.24	NNW	Channel tract	B
Fiji Point	zone D[6]	43.61	NE	Channel tract	B
Wreck Point	zone D[6]	223.44	SW	Channel tract	B

[1] Wagstaff & McEwen Mason (1989).
[2] Burger (1987).
[3] J. Douglas (personal communication 1986).
[4] Burger (1985).
[5] Geological Survey of Victoria (1973).
[6] Benedek & Douglas (1988, p. 225).

6 m deep in places, cut by the scouring action of the coarser material. Sediment-laden waters overspilled channel banks and deposited thick (up to 70 m) siltstone- and mudstone-dominated sequences in interchannel areas. Facies architecture, sediment composition, and texture suggest that the Apollo Bay deposits accumulated in a medial-fan to proximal braided-stream setting (Fig. 17).

Discussion

The common presence of granitic grit, subrounded to well-rounded schist pebbles, and weathered granite pebbles attests to erosion of nearby pre-Mesozoic basement, and transportation of the clasts several kilometres by water from an area northwest of Apollo Bay.

The maximum size of clasts in alluvial sequences is an indicator of proximity to source, according to Rust & Koster (1984), who used plots of maximum clast size versus distance from source to derive fields for modern alluvial-fan and alluvial-plain environments. The largest clasts observed at Blanket Bay and Marengo are granite, 25 cm in diameter, and fall within the area of overlap of fields from alluvial fans and braided rivers/alluvial plains. If system A is part of a fan, these clasts are 2 to 10 km from their source; if part of a braided river system, the range of distances may be much greater, up to 80 km.

Depositional system B

Moonlight Head and Rotten Point areas

Depositional system B is best developed along the coast northwest of Cape Otway. Near Moonlight Head (Fig. 1), system B lacks a basement-derived gravel component, and has palaeocurrent vectors markedly dissimilar to those of system A, which is older (Table 6). In addition, a greater, although still minor, proportion of lower-flow-regime deposits — mainly medium- to large-scale planar tabular cross-channel bars — is preserved in parts of depositional system B, although many other aspects of fluvial style are common to both systems.

Some features of the sequence at Rotten Point are common to systems A and B (Table 6). This sequence is about the same age as system A (*C. striatus* Zone), and has a southeasterly palaeocurrent vector mean. However, it lacks basement-derived gravel, and its multistorey channel-tract sandstone bodies are thinner than those of system A, but thicker than those of system B. The prevailing fluvial regime under which it evolved did not favour the development of coal swamps or incipient

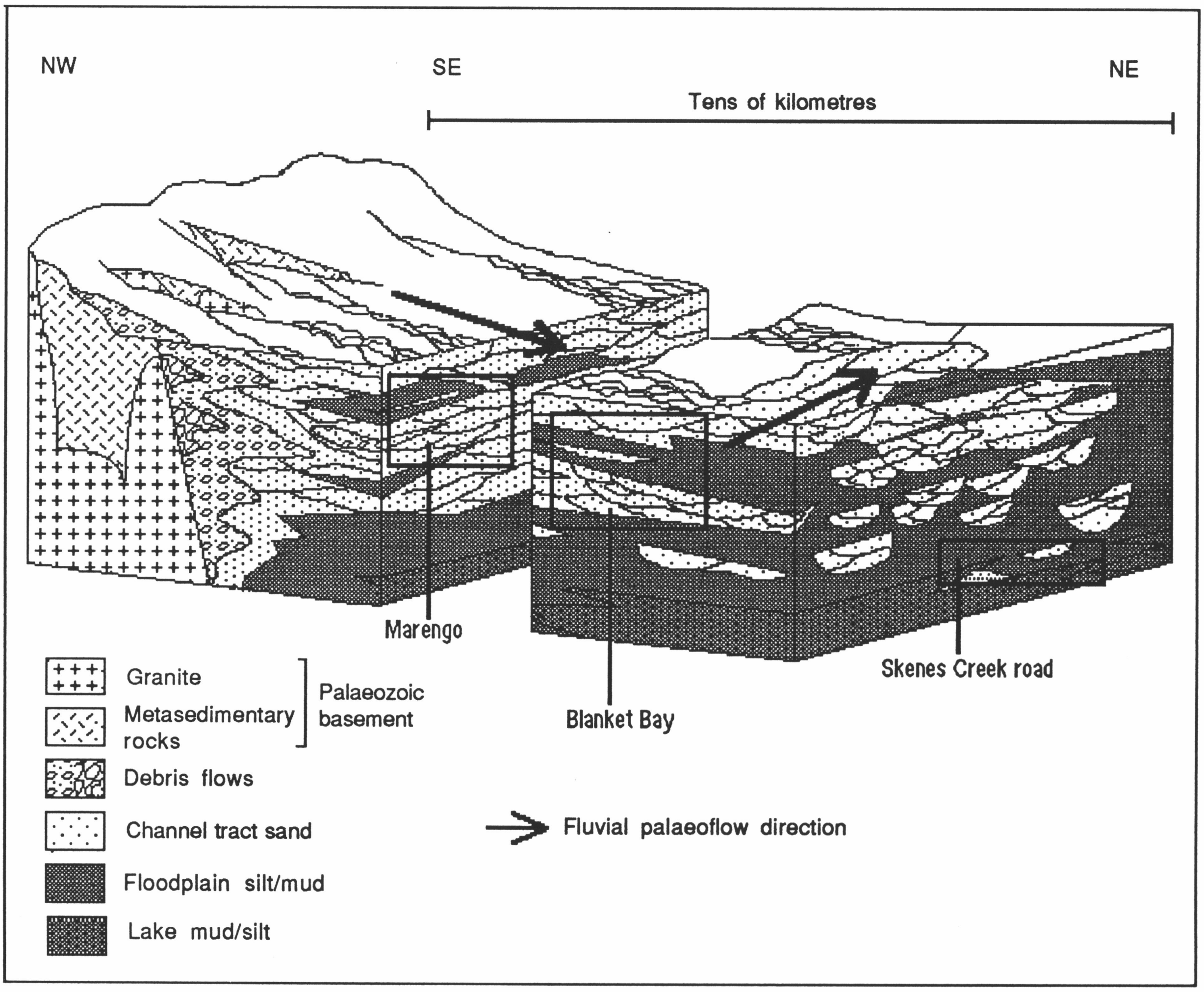

Figure 17. Block diagram of depositional system A: alluvial-fan/braid-plain deposition adjacent to structurally elevated basement.

soils, unlike system B. The sequence is interpreted as an older part of system B.

Discussion

Depositional systems in which sand-size and finer debris comprise the entire depositional products, and in which high-stage flows are the norm, are rarely described (e.g., Allen 1983; Tunbridge 1984); the few modern examples are attributed to rare catastrophic flooding whose depositional products are isolated within sediments reflecting more 'normal' depositional conditions (Osterkamp & Costa 1982), or are exposed to low-flow reworking or likely to undergo other substantial post-depositional modification (e.g., McKee et al. 1967). Most sandy systems described in the literature are characterised by low-flow-stage deposition of sand in braided or meandering streams subject to moderate hydrodynamic regimes (see reviews by Miall 1977; Walker & Cant 1984).

Such models are inappropriate for depositional system B, whose interpretation must rely on lithofacies, bedforms, and geometry. In system B, scour-and-fill accompanied the initial stages of floods which subsequently spread widely beyond the scour channels to form broad active stream tracts. System B is characterised by multistorey sandstone bodies up to 14 m thick, representing channel-tract deposition, separated by interchannel siltstones of similar thickness which locally contain thin coal beds, rooted horizons, and reddened soil profiles. The soil profiles, best developed immediately below thick sandstones, indicate that some interchannel (flood-plain) areas were inactive and exposed for long periods before they were reoccupied by new channel tracts.

This fluvial system is interpreted as a braid plain (Fig. 18). Multiple active stream tracts, dominated by upper-regime fluvial flow, were only weakly channelised. The absence of gravel (apart from mudstone intraclasts) in depositional system B is atypical of braid-plain deposition described in the literature (see Rust & Koster 1984 for a review of braid-plain sedimentology), but the lithofacies and bedforms of gravelly systems described by Rust & Koster (1984) are analogous to the depositional features of the Eumeralla sandy channel tracts. A number of features — namely, the dominance of sandy volcaniclastic sediment, rare pebbles of devitrified glassy volcanic rocks, and the local presence of possible debris-flow and hyperconcentrated stream-flow deposits — suggest that depositional system B was part of an apron flanking source volcanoes. Palaeocurrent vectors indicate that the volcanic sources were located southwest to southeast of Moonlight Head, perhaps in the axial part of the rift.

Depositional system C

North of Skenes Creek

Fluvial sedimentary rocks that crop out along 20 km of coastline between Skenes Creek and Lorne have some features in common with both systems A and B (Table 6), but have northwesterly palaeocurrent vectors and are interpreted as part of a third, distinct, depositional system (depositional system C). The ages of these outcrops are mainly early Albian (Wagstaff & McEwen Mason 1989), corresponding to the *C. striatus* and lower *C. paradoxa* Zones, but some are younger (*P. pannosus* Zone; Burger 1985).

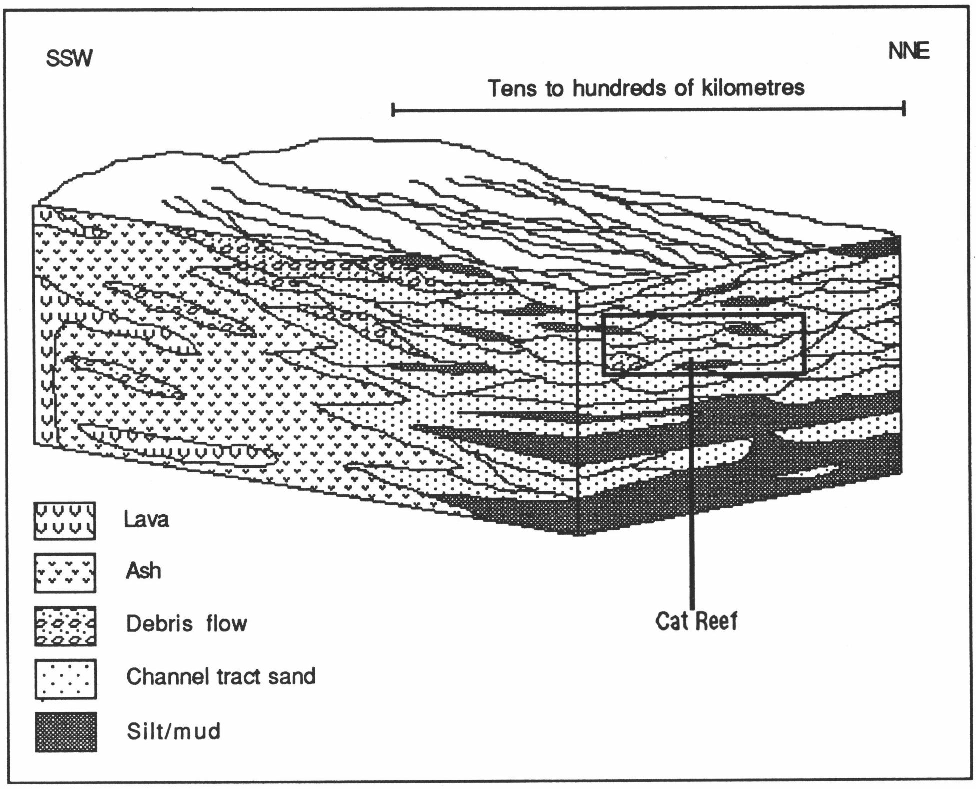

Figure 18. Block diagram of depositional system B: braid-plain deposition on the distal flanks of rift-axis volcanic complexes.

This system is sandstone-dominated (>90% of the coastal section), and its facies associations and fluvial architecture are similar to depositional system B. As for systems A and B, stream tracts of system C were dominated by upper-regime fluvial flow. Some channels initially were deeply scoured (up to 6 m at Cape Patton; Table 3), but the bases of most channels were flat or gently undulating (Figs. 3, 4a, 4b, 5).

The multistorey channel-tract sandstones of system C are several tens of metres thick (e.g., at Cape Patton; Table 3; see also Fig. 5). Dark grey interchannel siltstone and fine sandstone, where exposed, are seldom more than a few metres thick. Fossil soil has not been observed, but thin coal is locally preserved beneath channel bases (Fig. 3). Coalified logs up to 25 cm in diameter are common in the channel sandstones at many locations. These features indicate that system C consisted of large active channel tracts with fluctuating but probably perennial flow.

Discussion

This fluvial system is interpreted as representing a large braided river or possibly a braid plain. Unweathered volcaniclastic sandy detritus, which constitutes the bulk of the system, suggests that the major source of sediment supply was from contemporaneous volcanism, to the southeast. If this source was near the axis of the Otway rift, it was more distal to system C than to system B, consistent with the absence of debris flows and volcanic pebbles from system C.

System C might represent a late stage in the evolution of a formerly axial west-draining trunk stream (south of the present Otway Ranges) displaced to the north as volcanism developed at several locations along the rift axis. Alternatively, northerly drainage from extensive volcanic complexes near the rift axis south of Moonlight Head may have been diverted around the elevated basement block interpreted to have been present west of Apollo Bay. The presence of granitic and metamorphic clasts in gravel in system C could support either interpretation.

Other systems

Western Victoria

Exposures of fine-grained fluvial deposits at several localities in western Victoria consist mainly of siltstone, and subordinate thin sandstone with small-scale trough cross-bedding, indicating low-energy depositional conditions. Stacked soil profiles at one locality (see Felton 1992 for details) indicate long periods of exposure and low rates of sediment accretion. These sedimentary features are consistent with the interpretation of a distal braid plain, and the outcrops may represent the distal parts of system B.

A few outcrops indicate higher-energy depositional conditions in the fluvial system. They include a high proportion of basement-derived quartzose gravel. The well-rounded pebbles in the gravel may indicate second-cycle deposition and/or considerable transport. Most of these outcrops are mapped as part of the older *speciosus* microfloral assemblage of Dettman (1963; Geological Survey of Victoria 1971), but cannot otherwise be correlated with Eumeralla Formation outcrops elsewhere in the basin, or with the finer-grained outcrops, which are mapped as part of Dettman's (1963) *paradoxa* assemblage.

Barrabool Hills, west of Geelong

The northern Otway Ranges in the Barrabool Hills (fig. 3 in part I) consist of a fault-bounded elevated block composed of Palaeozoic basement and Eumeralla Formation rocks. Cobble beds containing rounded clasts of locally derived metasediments and greenstones near the faults are probably basal conglomerates in the Cretaceous (?Eumeralla Formation) sequence, but no contacts with basement are exposed. The cobble beds are interbedded with mud-draped pebbly cross-bedded quartz-lithic sandstone, poorly sorted and containing a volcaniclastic component. Eumeralla Formation mudstones higher in the same section along the Barwon River are dated as Albian on microfloral evidence (Cookson & Dettmann 1958).

The sequence probably represents part of an alluvial fan or valley fill flanking elevated basement, exposed less than 1 km away. Although it is not part of depositional system A, its setting is similar to but more proximal than the exposed parts of system A.

Conclusions

At least three discrete fluvial depositional systems are apparent in the Eumeralla Formation. Depositional systems A–C are distinguished by sediment composition, geography, age, sandstone geometry, and facies architecture.

The systems are sand-dominated. They are characterised by high-stage flow regimes, and 'flashy' discharge. Multistorey sandstones accumulated to tens of metres in thickness in broad active stream tracts which were largely unconfined by banks. The stream tracts have an overall braided character, but do not conform to published models of sandy braided stream systems. Bedforms and sedimentary structures are more akin to those of gravelly systems.

Depositional system C represents a northwest-flowing, formerly axial drainage in the Otway rift system. It was displaced to the north by the onset of axial volcanism and an associated volcaniclastic apron. System B is part of the epiclastic medial to distal apron formed on the northern flank of a volcanic complex on or near the rift axis. System A is of more local extent, and represents part of an alluvial fan flanking an elevated basement block of Palaeozoic metasediments and granite west of Apollo Bay. The block may also have contributed to displacement and diversion of a west-flowing trunk stream in the Otway rift towards the northern basin margin.

The depositional model proposed for the outcropping Eumeralla Formation implies that the contemporaneous volcanism which contributed the bulk of the detritus to the unit occurred largely at the rift axis. Sedimentary evidence suggests that at least one substantial volcanic complex was located southwest of Cape Otway, probably close to the present-day shelf edge. Other volcanic complexes farther southeast supplied epiclastic detritus to system C.

Acknowledgments

I thank Professor Alan Cook, former Head of the Department of Geology, the University of Wollongong, for encouraging me to undertake a PhD study of the Otway Basin; and my supervisor, Dr Brian Jones, for advice, encouragement, and the opportunity to examine modern braided ephemeral river systems in northern Australia in 1988. I also thank Mr John Cramsie and Dr Bob Dalgarno, who, as successive Directors of the Geological Survey of Victoria, permitted me to examine and sample core and cuttings from the Otway Basin. I thank staff at government core laboratories in Victoria, South Australia, and the ACT for their assistance in locating relevant material, in particular Mr Joe Staunton of the Core & Cuttings Laboratory, Canberra, ACT.

The PhD study was undertaken with the assistance of a Commonwealth Postgraduate Study Award during 1986–1988.

References

Allen, J.R.L., 1983. Studies in fluviatile sedimentation: bar-complexes and sandstone sheets (low-sinuosity braided streams) in the brownstones (L. Devonian), Welsh Borders. Sedimentary Geology, 33, 237–293.

Allen, J.R.L., 1984. Sedimentary structures. Their character and physical basis. Elsevier, Amsterdam.

Benedek, S. & Douglas, J.G., 1988. Otway Basin, eastern part. In: Douglas, J.G. & Ferguson, J.A. (editors), Geology of Victoria. Geological Society of Australia, Melbourne, 222–228.

Burger, D., 1985. Palynological report on samples from Holtzers Quarry, Otway Basin, Victoria. Bureau of Mineral Resources, Australia, Professional Opinion, Geology, 85.004

Burger, D., 1987. Palynological examination of samples from the Otway Group in the Otway Basin, Victoria. Bureau of Mineral Resources, Australia, Professional Opinion, Geology, 87.006

Cant, D.J. & Walker, R.G., 1976. Development of a braided fluvial facies model for the Devonian Battery Point Sandstone, Quebec. Canadian Journal of Earth Science, 13, 102–119.

Cant, D.J. & Walker, R.G., 1978. Fluvial processes and facies sequences in the sandy braided South Saskatchewan River, Canada. Sedimentology, 25, 625–648.

Cookson, I.C. & Dettmann, M.C., 1958. Some trilete spores from upper Mesozoic rocks from the eastern Australian region. Proceedings of the Royal Society of Victoria, 70, 95–128.

Dettman, M.E., 1963. Upper Mesozoic microfloras from southeastern Australia. Proceedings of the Royal Society of Victoria, 77, 1–148.

Douglas, J.G., 1969. The Mesozoic floras of Victoria, parts 1 and 2. Geological Survey of Victoria, Memoir 28.

Douglas, J.G., 1986. The Cretaceous vegetation and palaeoenvironment of the Otway Group sediments. In: Glenie, R.C. (editor), Second southeast Australia oil exploration symposium. Petroleum Exploration Society of Australia, 233–240.

Felton, E.A., 1992. Sedimentary history of the Early Cretaceous Otway Group, Otway Basin, Australia. PhD Thesis, The University of Wollongong, Wollongong, Australia.

Friend, P.F., 1983. Towards the field classificiation of alluvial architecture in sequence. In: Collinson, J.D. & Lewin, J. (editors), Modern and ancient fluvial systems. International Association of Sedimentologists, Special Publication 6, 345–354.

Friend, P.F., Slater, M.J., & William, R.C., 1979. Vertical and lateral building of river sandstone bodies, Ebro Basin, Spain. Journal of the Geological Society, London, 136, 39–46.

Geological Survey of Victoria 1971. Hamilton 1:250 000 geological sheet SJ54–7. Geological Survey of Victoria, Melbourne, Australia.

Geological Survey of Victoria 1973. Colac 1:250 000 geological sheet SJ54–12. Geological Survey of Victoria, Melbourne, Australia.

Jones, B.G., 1970. A computer programme for analysing directional data designed for use on a CDC3600. Bureau of Mineral Resources, Australia, Record 1970/67.

Kesel, R.H., Dunne, K.C., McDonald, R.C., Allison, K.R. & Spicer, E., 1974. Lateral erosion and overbank deposition in the Mississippi River in Louisiana caused by 1973 flooding. Geology, 2, 461–464.

Leopold, L.B. & Wolman, M.G., 1957. River channel patterns: meandering, braided and straight. United States Geological Survey, Professional Paper 282–B, 1–85.

McKee, E.D., Crosby, E.J. & Berryhill, H.L., 1967. Flood deposits, Bijou Creek, Colorado. Journal of Sedimentary Petrology, 37, 829–851.

Medwell, G.J., 1977. Palaeocurrent directions on Otway Group sediments, Otway Ranges, southeastern Australia. Proceedings of the Royal Society of Victoria, 89, 27–50.

Medwell, G.J., 1988. Otway Ranges. In: Clark, I. & Cook, B.J. (editors), Victorian geology excursion guide. Australian Academy of Science, 133–156.

Miall, A.D., 1977. A review of the braided river depositional environment. Earth Science Reviews, 13, 1–62.

Miall, A.D., 1978. Lithofacies types and vertical profile models in braided river deposits: a summary. In: Miall, A.D. (editor), Fluvial sedimentology. Canadian Society

of Petroleum Geologists, Memoir 5, 597–604.
Miall, A.D., 1985. Architectural element analysis: a new method of facies analysis applied to fluvial systems. Earth Science Reviews, 22, 261–308.
Osterkamp, W.R. & Costa, J.E., 1982. Changes accompanying extraordinary flood in a sand-bed stream. In: Mayer, L., (editor), Catastrophic flooding. Binghamton Symposia in Geomorphology, International Series, 18. Allen & Unwin, Boston, 201–224.
Popov, I.V. & Gavrin, Y.S., 1970. Use of aerial photography in evaluating the flooding and emptying of river flood plains and the development of flood-plain currents. Soviet Hydrology, 5, 413–425.
Rust, B.R. & Koster, E.H., 1984. Coarse alluvial deposits. In: Walker, R.G. (editor), Facies models, second edition. Geoscience Canada Reprint Series, 1, 53–69.
Schumm, S., 1960. The shape of alluvial channels in relation to sediment type. United States Geological Survey, Professional Paper, 352–B, 17–30.
Schumm, S., 1972. Fluvial palaeochannels. In: Recognition of ancient sedimentary environments. Society of Economic Paleontologists and Mineralogists, 16, 98–107.
Simpson, C. & Doutch, H.F., 1977. The 1974 wet–season flooding of the southern Carpentaria Plains, northwest Queensland. BMR Journal of Australian Geology & Geophysics, 2, 43–52.
Smith, N.D., 1971. Transverse bars and braiding in the lower Platte River, Nebraska. Geological Society of America, Bulletin 82, 3407–3420.
Struckmeyer, H.I.M. & Felton, E.A., 1990. The use of organic facies for refining palaeoenvironmental interpretations: a case study from the Otway Basin, Australia. Australian Journal of Earth Sciences, 37, 351–364.
Tunbridge, I.P., 1984. Facies model for a sandy ephemeral stream and clay playa complex: the Middle Devonian Trentishoe Formation of north Devon, U.K. Sedimentology, 31, 697–715.
Wagstaff, B.E. & McEwen Mason, J., 1989. Palynological dating of Lower Cretaceous coastal vertebrate localities, Victoria, Australia. National Geographic Research, 5, 54–63.
Walker, R.G. & Cant, D.J., 1984. Sandy fluvial systems. In: Walker, R.G. (editor), Facies models, second edition. Geoscience Canada Reprint Series, 1, 71–89.

Appendix. Profile descriptions

The profiles described below are representative of Eumeralla lacustrine and fluvial systems. They are located in Figure 1, and supported by keys presented in Figure 2 (for the long profiles) and figure 11 in part I of this paper (for the vertical profiles). Bedding contacts are classified according to the hierarchical system of Allen (1983).

Cape Patton

Profile CP1 (Fig. 3; Figs. 4a, 4b). Profile CP1, in a road cutting at Cape Patton (Fig. 3), is 14 m long and 11 m high and trends 070°, roughly normal to the depositional dip (towards 340°; away from camera). Figures 4a and b are continuous with profile CP1, but at a larger scale. They illustrate the passage of a basal channel sandstone body into levee siltstones at its right-hand margin. An overlying channel sand also passes laterally into a levee sequence containing thin fining-upward splay sand beds. The levees have an apparent dip away from the channel sandstones owing to the greater compaction of interbedded finer sediments.

Bedding contact **a** (Fig. 3) is a concordant to discordant erosional third- or higher-order contact at the base of a sandstone body at least 12 m thick overlying sediments of lithofacies Fl, Fm, and C (Table 2). Erosional relief on contact **a** is probably less than 50 cm. Other major bedding contacts in the profile are planar concordant to discordant erosional surfaces, usually truncating zeroth-order internal lamination in underlying beds. Contact **e** truncates fining-upward bed **de**, and is probably second order, but all other bedding contacts are first order.

Most individual beds consist of single plane-bed or low-angle cross-bed sets (lithofacies Sh and Sl) 70 cm to 1.2 m thick, which are sheet-like or elongate lenticular within the length of the outcrop (60 m). These beds are probably simple plane-bedded bars. Shallow scours in places are filled by lithofacies Ss (**ab**, **ef**, **ij**).

Holtzers quarry

Profile HQ1 (Fig. 5). This profile is exposed in a quarry face trending 250°, 50° oblique to the vector mean palaeocurrent direction of 300° (away from camera) determined from measurements at the base of the opposite face of the quarry. Apparent structural dip is to the right (true dip is 30°/140°). The profile is about 50 m long and 12 m high. The total height of the quarry face is about 30 m.

The nature and extent of many low-order bedding contacts cannot be ascertained with certainty. Most appear to be first-order concordant to discordant erosion surfaces bounding plane-bed or low-angle cross-bed sets (**h**, **i**, **k**, **e**, **f**, **g**, **c**); **o** may be a reactivation surface.

d is a second- or third-order bedding contact defining the base of a channel form. Its oblique cross-section width in outcrop is about 30 m, and its depth 4 m. A lateral component is apparent in the channel fill **do**, which consists of lithofacies Sh and Sl. **l** may be a lateral accretion surface. **dj** is a small low-angle bed set in the channel base.

Facies Sl and Sh are prominent in the sandstone underlying the channel. Intervals **ef** and **fg** may be parts of large cross-bed sets or the low-angle margins of bars. Intervals **ac** and **cd**, which extend laterally for several tens of metres and are 2 to 3 m thick, are probably simple plane-bedded bars.

Elsewhere in the quarry, but not apparent in the profile, small-scale trough and planar tabular cross-bed sets, up to 35 cm thick, are locally developed in silty sandstone at the tops of plane-bed cosets; they are usually isolated single sets, or consist of two to three sets separated by reactivation surfaces. Thin intervals of laminated mudstone and siltstone may drape their tops, and commonly pass laterally into a thin layer of mudclasts (lithofacies Gs) at the base of a succeeding plane-bed set. Small-scale cross-bedded sandstone a few centimetres thick may be interbedded with the mudstone and siltstone.

The exposures in the quarry are interpreted as part of the channel tract of a large river in which rising floodwater or increasing flows cut shallow channels in underlying sands. Plane-bed cosets topped by cross-beds represent large compound bars developed during upper-regime fluvial flows. Flow fluctuations and waning flows promoted deposition of the cross-bedded finer-grained sediments atop the bars; mud and silt were deposited during periods of slack-water.

Rotten Point

Profile RP1 (Fig. 6). Profile RP1 is located on the eastern side of a small headland 150 m east of Rotten Point. The profile is 44 m long. About 10 m of vertical section is exposed, including units 10, 11, and 12 in the vertical profile RP3 (Fig. 8); intervals **ai**, **ij**, and **jl** are units 10, 11, and part of 12 respectively. The trend of the profile is 240°, 60° oblique to the depositional dip towards 180° (to the left). True structural dip is 22°/300° (away from the camera).

Profile RP1 consists of lithofacies Sh, Sl, and rarely St (70% of section), which sharply fine upwards into Sr, Fl, and

Fm (30% of section).

Bedding contacts **a**, **i**, and **j** are concordant to discordant erosional surfaces of third order or higher. **c**, **f**, and **g** are second-order erosional contacts forming the lower boundaries of small, fine- to medium-grained sand-filled channel forms. **e** is also a second-order contact at the base of a thin laminated and rippled sandstone sheet within interval **ai**. Other contacts (**b**, **k**, and **l**) are first-order concordant to discordant erosional to non-erosional surfaces bounding plane-bedded sandstone sheets within thicker sandstone/mudstone sheets (intervals **ai**, **ij**, and **jl**) bounded by higher-order contacts.

The sandstone/mudstone units are interpreted as the products of sheet-floods which, during high-stage flow, deposited considerable thicknesses of laminated sand as essentially unchannelled sand sheets on a flat fluvial plain, such as a braid plain or distal alluvial fan. Six probable floods can be identified in units 10–12 (Fig. 8). Flow waned abruptly, but deposition of fine sand, silt, and mud continued, and built up considerable thicknesses of sediments (up to 2 m compacted thickness), too thick to be attributed to a single flood. Much accumulated fine sediment might have been supplied by periodic overbank deposition from remote fluvial channel tracts (e.g., upper half of unit 10; Fig. 8). Some sediment might have been deposited by overbank deposition from minor flood-plain distributaries, represented in the profile by the small sandstone-filled channel forms bounded by surfaces **g** and **h**.

Profile RP2. Profile RP2 (Fig. 7) exemplifies the nature of deposition in part of a 35-m-thick sandstone forming cliffs 30 m high 500 m east of Rotten Point. The top of the outcrop illustrated in Figure 7 lies about 5 m below the base of profile RP3 (Fig. 8), in which units 1–9 constitute the top of the thick sandstone.

The outcrop comprising RP2 is inaccessible to detailed examination, so that depositional and structural dip could not be determined from actual outcrop measurement. Structural dip is assumed to be 22°/300°, the same as much of the Rotten Point sequence nearby. The depositional dip is assumed to be oriented about 170°, according to the vector mean palaeocurrent direction determined for units 1–7 in RP3 (Fig. 8). Profile RP2 trends 190° (to the right of Fig. 7), and so is oriented about 20° oblique to the depositional dip, away from the camera. It represents about 5 m of section, and is 13 m long.

Mainly first-order bedding contacts appear to be present in RP2, which consists almost entirely of low-angle cross-beds (lithofacies Sl) with similar orientations. The surfaces are concordant to discordant erosional, and truncate zeroth-order contacts within individual beds; most are subparallel to one another, and define principal bedding in the sequence. Contacts **d** and **l** may be second-order contacts; they are locally scoured, and separate beds with distinctly different orientations of laminae which reflect different palaeocurrent vectors.

Intervals **de** and **lm** are scours filled by lithofacies Ss. All other beds are sheets or elongate lenses ranging in thickness from 20 to 60 cm. In beds **df**, **hj**, **jk**, and **mn**, the internal laminae reverse their dip direction over a few metres. In other beds (e.g., **bd**), the dip angle of internal laminae varies along the bed, and locally is parallel to the bed base. Also, in beds **jl** and **lo**, dip angles of internal laminae steepen toward the bed top, and the laminae increase in thickness.

In the centre and right of bed **bd**, the gently dipping internal laminae thicken downdip to an estimated maximum of 15 cm where they meet the base of the bed. Similar thickened beds in lithofacies Sl in unit 4 of profile RP3 (Fig. 8) consist of laterally persistent interbeds of internally laminated upper fine-grained (to 15 cm thick) and lower coarse-grained (to 20 cm) sandstone (Fig. 9). One interbed 15 cm thick consists of climbing-ripple fine-grained sandstone with mud flasers (Fig. 10); the basal contact of overlying coarse sandstone is load-casted into the finer unit.

The beds in RP2 are interpreted as low-relief cross-bedded simple bars deposited in upper-flow-regime conditions. The low angle of the cross-bedding is due to suppression of flow separation at the bar margins. Lateral and oblique accretionary growth of the bar margins relative to mean palaeocurrent direction is evident from the development of thickened laminae in bed **bd**, and is inferred from the predominance of low-angle cross-bedding in other beds. Although some of the plane-bedded tops of bars have been removed by erosion, I suspect that only small amounts of sand were deposited on the bar tops, and that most deposition took place on the downstream and side margins of bars in conditions of somewhat lower (but still upper- or transitional-stage) flow regime than that prevailing on the bar top. Small-period fluctuations in flow along the sides and fronts of bars promoted the development of thicker laminae and thin beds as sediment was dumped in conditions of lower flow.

Profile RP3 (Figs. 8–10). The succession at Rotten Point represents deposition in an active flood basin, probably on a braid plain. Units 1–9, the upper part of a multistorey channel-tract sandstone 35 m thick, are representative of deposition throughout the sandstone. Units 8–9 record abandonment of the active channel. The remaining 62 m consists of fining-upward sheet sandstones of different thicknesses — probably splay sandstones spilt from sandy channels during floods — separated by intervals of laminated and rippled siltstone; units 10–12 are illustrated in Figure 6. Bioturbation, soft-sediment deformation, and water-escape features also attest to frequent inundation.

The absence of coal beds and pedogenic features distinguishes the environment of this flood-plain sequence from that represented in Cat Reef profile CR1.

Cat Reef

Profile CR1 (figs. 15–17 in part I). This profile is described in part I. The base of unit 3 corresponds to the bedding contact **aa** in profile CR2.

Profile CR2 (Fig. 11). The Cat Reef locality, in the youngest known part of the exposed Eumeralla Formation, is close to the western limit of the Otway Ranges coastal outcrops (fig. 3 in part I). The cliff face exposure illustrated is 10 m high and 55 m long; it trends 330°, roughly normal to the trends of the major channels (030°). The calculated vector mean palaeocurrent direction of 340° for the entire Cat Reef section (Felton 1992, appendix 4A) diverges from vector means calculated for individual units from the lower part (units 3, 4, 7, and 8 of fig. 15 in part I), including this profile. The structural dip of the profile is 15°/290° (towards and to the left of the camera).

Overall, the section at Cat Reef/Fiji Point consists of 93 per cent sandstone, including rare thin lenticular muddy siltstones filling shallow depressions in the tops of sandstone storeys. The remaining 7 per cent consists of siltstone and mudstone, pedogenised in part (fig. 18 in part I), thin lenticular sandstones, and rare beds of carbonaceous mudstone and coal.

Two large channel forms (**ae** and **ey**), filled by medium- and coarse-grained sandstone with local gravel, are major features of profile CR2. Both **a** and **e** are third-order, broadly concave-up bedding contacts at the bases of the two channels. The relationship of **a** to the right-hand channel, **ae**, is not apparent from the profile, but this major scour surface can be traced across the wave-cut platform in the foreground to the base of a headland about 10 m to the right of CR2. The scour surface is overlain by a sandstone-intraclast boulder and pebble bed (base of unit 3, fig. 15 in part I; see also fig. 16 in part I). If surface **a** in the profile, including its associated sandstone-intraclast boulders, lay close to a channel cutbank margin, the total channel width must have exceeded 60 m.

The fill of **ae**, mainly plane-bedded sandstone, is at least 8 m thick, and the deepest part of the channel, at the right of the profile, about 10 m across. Shallower parts of the channel are filled by plane-bed and low-angle cross-bed sets (**bc** and **cd**; which are laterally equivalent to the upper part of unit 3 in figs. 15 and 16 in part I) in which chute-and-pool backset cross-beds locally overlie **a** (fig. 16 in part I). The first-order discordant erosional bounding surfaces of **bc** and **cd** roll over into the main channel to become concordant with the channel-fill laminae, and ultimately merge with them. **bc** and **cd** are interpreted as broad low-relief bars which developed in shallower parts of the channel, probably during flood-falling stage (but still in upper-regime flow conditions). The bars, growing by lateral and forward accretion, prograded laterally into the adjacent deeper channelised part of **ae**, which probably formed by scour during initial stages of a major flood. Sedimentation in the channel may have been continuously vertically accreting, without the development of bars, in conditions of upper-regime flow.

The size and form of channel **ey**, and the organisation of its sedimentary fill, are similar to those of **ae**. Surface **e** has associated siltstone intraclasts (lithofacies Gs), and defines deeper and shallower parts of a scour channel at least 60 m across with a deep section 11 m across. The shallower part of the channel is filled mainly by single sets of Sl and Sh, some of which flank a larger plane-bed set (**fg**) of minimum thickness 3.4 m. The upper bounding surface of this set, a second-order concordant to discordant erosional surface, separates larger and smaller bedforms. **fg** is thought to represent part of a large plane-bedded simple bar that developed in the channel at high-flood-flow stage, and was partly eroded during a lower stage — perhaps after a fairly rapid decline in flow strength when smaller bedforms grew around (**gh'**, **gh**) and across (**h'i**) it. At least some of these bedforms, probably small bars, also prograded laterally into channel **eq**; bedding contacts and bedforms cannot be readily traced across the central fault-bounded block into the marginal part of channel **eq**, but surface **p**, a possible correlative of **i**, rolls over and merges with bedding in **eq** in a similar manner to surfaces **c** and **d** in channel **ae**. The large bar **eg** probably wedges out on the deep channel margin near the convex-upwards part of surface **f**.

Above the deep channel **eq**, planar tabular sandstone sets 1 m thick or less comprise the bulk of the remaining exposed channel-fill; some sets may extend across the entire width of the channel (e.g., **kl** and a possible correlative in the sequence, **qy**). The planar tabular sets formed and grew in lower-flow-regime conditions following the flood peak. A brief scouring episode is recorded by scour-fill unit **tv**.

This profile represents part of a fluvial-channel-tract sandstone. Simple and complex plane-bedded bars are the main bedforms, developed during consistent upper-regime flows. Flow fluctuations influenced the local development of dunes and simple bars in lower-flow-regime conditions, and, during periods of high or rapidly rising flows, might have promoted the scouring of broad and shallow channel forms that were later filled by migrating bars. Mass flows and hyperconcentrated flood flows may have presaged the larger floods.

Johanna Beach

Profile JB1 (Fig. 12). Profile JB1 is a cliff section 47 m long that trends about 350°, about 20° oblique to the depositional dip direction of 007°, which is away from the camera; 10 m of vertical section is exposed. The apparent structural dip is about 20° to the right.

Two subparallel third- (or higher-) order (**b**) and second-order (**p**) bedding contacts are about 8 m vertically apart. **p** is a low-relief discordant to concordant contact which extends for at least 40 m in outcrop. **b** is a discordant erosional contact, and has a relief of at least 2 m; in places up to 2.5 m of silty mudstone (Fl and Fm) are preserved beneath the contact. The mudstone rests disconformably on another sandstone body (**ab** in profile), but, in the profile as figured, has been eroded and redistributed as lithofacies Gs along the contact.

Contact **b** has been traced 300 m east to the end of Johanna Beach and possibly extends west for about 1.5 km to a headland where it appears above a recessive unit at the base of a cliff. The overlying sandstone here has an estimated thickness of 13 m. The sandstone at Johanna Beach is equivalent to the basal part of this sandstone body.

In profile JB1, most bedding surfaces are concordant to discordant erosional, and are identified as first-order contacts. Lithofacies Sh and Sl are dominant; Ss is locally developed in scours. **bh**, apparently a sandstone sheet or elongate lens, is probably a large plane-bedded bar.

Discontinuous minor surfaces (**f** and **g**) are interpreted as reactivation surfaces. **f** bounds a shallow scour (minor channel) fill. **c** and **d** may also be reactivation surfaces, or the margins of downstream accreting sandy bedforms, probably simple bars.

First-order contacts **h** and **j** have local erosional relief of about 1 m on top of the sandy bedform **bh**. Scour-filling units **be** and **hk** consist of lithofacies Ss. Units **jk**, **kl**, and probably **hm** are plane-bedded bars of various scales. Cross-strata in **jk** may locally approach avalanche steepness. Minor surfaces **n** and **o** are interpreted as reactivation surfaces.

bh and **hp** resemble the plane-bedded simple bars from the Devonian Welsh brownstones, illustrated in summary by Allen (1983, fig. 12b). Like the bars in the brownstones, they have variably scoured lower contacts and numerous reactivation surfaces. However, where plane bedding rolls over into accretionary foresets, these dip at 10° or less.

Plane-bedded bars dominate this profile, which represents the basal part of a channel-tract sandstone. Cross-bedding at bar margins ('foresets') has a low angle, and implies extremes of high-stage flow accompanying deposition. The basal third-order scour surface observed defines a number of scour hollows a few square metres in area but is only weakly channelised. The channel tract is interpreted as broad and shallow, and as having essentially unconfined fluvial flow over a flat or low-slope alluvial plain.

Blanket Bay

Profile BB1 (Fig. 13). Profile BB1 represents two channel-tract sandstone sequences separated by flood-plain and lacustrine deposits. Units 5–9 record the depositional history of the flood plain.

Stacked fining-upward cycles of sandstone to mudstone are dominant in units 5–6. They record the final abandonment of the underlying channel tract (unit 5), and drowning of the abandoned channel by a flood-plain lake (unit 6). The accumulation of lacustrine mud and silt (units 7–8) was interrupted frequently by incursions of fine sand (especially in unit 7). The burrowed and bioturbated unit 7 probably represents deposition in a shallow lake. The upward decrease in rippled intervals in unit 8 may record deepening of the lake; the upper 10 m is ripple-free.

In addition to its increasing grainsize, the overall coarsening-upward unit 9 includes ripple laminae succeeded by a climbing-ripple interval, and reflects increasing energy in the system. Bioturbated beds indicate either or both shallowing of the lake or an increased nutrient supply. The succeeding channel-tract sandstone (unit 10) is thinner than other channel-tract sandstones (at least 70 m thick; Felton 1992) in the Blanket Bay area, and has a palaeocurrent vector mean which differs from that in units 1–4; it may be a large splay or distributary channel.

Browns Creek

Profile BC1 (Fig. 14). The profile was measured at one end of a wave-cut platform 700 m long in which the sheet-like geometry of the bedding was accentuated by preferential carbonate cementation of the thin sandstones present. Most of its units extend laterally for several hundred metres subparallel to the depositional dip.

Laminated siltstone (lithofacies Fl) is the dominant rock type. Wavy lamination and local rippled coarse silt laminae are the only other sedimentary structures. Single ripple sets 1 to 3 cm thick are common. Straight-crested ripples are confined to fine-grained intervals in the lower half of the profile; in the upper half, only sinuous-crested ripples were found. Both ripple types have north-northwesterly palaeocurrent directions similar to the north-northwesterly directions indicated by trough cross-strata.

Units 1–3 represent lacustrine deposition. The rippled thin sandstone bodies at the tops of units 1 and 2 are lenticular, and have gradational bases and tops. The gradational tops consist of sharply fining-upward structureless sandy siltstone 20 cm thick. The sandstone bodies are enclosed by laminated mudstone and siltstone of probably lacustrine origin. They are interpreted as the mouth bar deposits of a small distributary developed during the lowstand of a flood-plain lake.

Unit 3 consists of laminated lacustrine siltstone which coarsens upwards to very fine sandstone with a sharp planar top, which is succeeded by carbonaceous marsh mudstone. The sandstone is a distributary mouth bar deposit similar to those described above, but represents a lake-filling episode culminating in marsh deposits which are partly eroded by a small splay or distributary channel.

Units 4–7 are probably flood-plain deposits. Units 6 and 7 are sheet sandstones which fine upwards through rippled and laminated fine sandstone, siltstone, and mudstone to rare thin carbonaceous mudstone and coal. The basal contacts of these sheet sandstones are sharp, planar to locally concave-upward, and overlie lithofacies Fl and Fm. Because of their extent, they are interpreted as medial to distal-splay and/or sheet-flood sands which spread over essentially flat flood-plain surfaces that were locally scoured. Unit 4 appears to be lenticular; it is not as extensive as units 6 and 7, and may be a distributary channel.

Units 8 and 9 probably represent a return to shallow lacustrine conditions. The composite sand body represented by units 10–11 contains several cosets of small trough cross-beds, and may be a proximal splay or small flood-plain distributary channel.

Skenes Creek Road

Profiles SCR1, SCR2, SCR3 (figs. 11–14 in part I). These profiles are described in part I of this paper. They represent parts of a flood-plain/lake sequence.